



## NASA SBIR 2011 Phase I Solicitation

### Exploration Systems

#### In Situ Resource Utilization Topic X1

The purpose of In-Situ Resource Utilization (ISRU) is to harness and utilize resources at the site of exploration to create products and services which can enable and significantly reduce the mass, cost, and risk of near-term and long-term space exploration. The ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can significantly reduce the cost, mass, and risk of sustained human activities beyond Earth. The ability to modify the landscape for safer landing and transfer of payloads, creation of habitat and power infrastructure, and extraction of resources for construction, power, and in-situ manufacturing can also enable long-term, sustainable exploration of the solar system. Since ISRU can be performed wherever resources may exist, both natural and discarded, ISRU systems will need to operate in a variety of environments and gravitations. Also, because ISRU systems and operations have never been demonstrated before in missions, it is important that ISRU concepts and technologies be evaluated under relevant conditions (gravity, environment, and vacuum) as well as anchored through modeling to regolith/soil and environmental conditions. While the discipline of ISRU can encompass a large variety of different concept areas, resources, and products, the ISRU Topic will focus on technologies and capabilities associated with solid in-situ material handling and processing along with atmospheric and trash/waste processing.

Sub Topics:

#### X1.01 In-Situ Resource Characterization, Extraction, Transfer, and Processing

Lead Center: JSC

Participating Center(s): GRC, KSC, MSFC

The ability to characterize, collect, transfer, and process resources at the site of exploration on the Moon, Mars, and Near Earth Objects (NEOs)/Phobos can completely change robotic and human mission architectures. The subtopic seeks proposals for the design and subsequent build of hardware and technologies that perform critical functions and operations for characterization, collection, transfer, and processing operations that can be inserted for integration into on-going and future system-level development and demonstration efforts. The technologies and hardware must utilize local materials with the minimum Earth-supplied feedstock possible. There are three main areas of interest:

#### Extraterrestrial Material-Based ISRU

- Methods for collection and transfer of NEO/Phobos material under micro-gravity conditions under vacuum/space environmental conditions. Proposals must state and explain material properties and water content considered in the design.
- Methods for the transfer of Mars surface material containing water at 1 to 5 kg/hr under Mars surface environmental conditions. Proposals must state and explain material properties and water content considered in the design, and locations on Mars where the method proposed is applicable
- Use of ionic liquids for processing and extracting oxygen and metals from extraterrestrial material at

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temperatures below 200 C at 0.2 kg/hr. Proposals must include methods for product separation and ionic liquid reagent regeneration for subsequent processing.

- Development of reactors with dust tolerant gas-tight seals and valving to extract and collect of water and other potential volatiles from extraterrestrial materials at 0.5 to 5 kg/hr of material processing rate. Proposals must state and explain material properties, water content, mixing technique, and gravity conditions considered in the design. Proposals may combine material transfer with water/volatile processing to minimize mass and power. Proposals for processing reactor systems should focus on highly effective approaches to energy utilization, including internal heat and mass transport enhancements and/or other physical or operational characteristics. Proposals that cover more than one material for consideration are of particular interest.
- Development of a compact, lightweight gas chromatograph - mass spectrometer (GC-MS) instrument that can quantify volatile gases released by sample heating below atomic number 70 (of particular interest H<sub>2</sub>, He (and isotopes), CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>O, N<sub>2</sub>, O<sub>2</sub>, Ar, NH<sub>3</sub>, HCN, H<sub>2</sub>S, SO<sub>2</sub>). The instrument should be designed to be able to withstand exposure to the release of HF, HCl, or Hg that may result from heating regolith samples to high temperatures. The instrument should be capable of detecting 1000 ppm to 100% concentration of the volatiles in the gas phase. The instrument should have a clear path to flight with a flight instrument design with a mass of less than 5 kg not including any vacuum components required to operate in the laboratory environment.

### **Extraterrestrial Atmosphere Based ISRU**

- Devices that collect and separate Mars atmospheric argon and nitrogen using a standalone device or as part of carbon dioxide collection concepts at carbon dioxide collection rates (0.5 to 2 kg CO<sub>2</sub>/hr rate and supply pressure at >15 psi for subsequent processing).
- Micro-channel reactor and heat exchanger concepts for efficient processing of carbon monoxide and carbon dioxide into water and/or methane with hydrogen at 0.5 to 2 kg/hr rate.

### **Discarded Material-Based ISRU**

- Trash processing reactor concepts for production of carbon monoxide, carbon dioxide, water, and methane from plastic trash and dried crew solid waste. Proposals must define use of solar or electrical energy during processing, and any reagents/consumables. Recycling schemes for reactants/reagents used in the processing should be included. Highly efficient, compact water vapor removal/separation devices from product gas streams is also of interest.

Proposals must consider the physical/abrasive, mineral, and volatile/water properties and characteristics of the material/resource of interest, and the gravity environment in which collection, transfer, and processing will occur. Concepts that can operate in micro & low-gravity (1/6-g & 3/8-g), as well as multiple resources are of greater interest. Designs that are compatible for subsequent analog, micro/low-g flight experiments, and ground vacuum experiments are also of greater interest. Proposals that utilize rotating gears and actuators must be designed for abrasive/dusty environmental conditions. Proposals will be evaluated against state-of-the-art capabilities with respect to mass, power, and process efficiency. Figures of merit include consumable production rate (kg/hr), production energy efficiency (kg produced/ hr per KWe), and extraction/reactant recovery efficiency.

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## Propulsion Topic X2

Human Exploration requires advances in propulsion for transport to the moon, Mars, and beyond. A major thrust of this research and development activity will be related to space launch and in-space propulsion technologies. These efforts will include earth-to-orbit propulsion, in-space chemical propulsion, in-space nuclear propulsion, and in-space electric propulsion development and demonstrations. NASA is interested in making propulsion systems more capable and less expensive. NASA is interested in technologies for advanced in-space propulsion systems to support exploration, reduce travel time, reduce acquisition costs, and reduce operational costs.

Sub Topics:

### **X2.01 Low Cost Heavy Lift Propulsion**

**Lead Center: MSFC**

**Participating Center(s): GRC, KSC**

Heavy lift launch vehicles envisioned for exploration beyond LEO will require large first stage propulsion systems. Total thrust at lift-off in will probably exceed 6 million pounds. There are available, in-production, practical propulsion options for such a vehicle. However, the cost for outfitting the booster with the required propulsion systems is in the hundreds of millions of dollars (2011 \$). This cost severely limits what missions NASA can perform. Low cost design concepts and manufacturing techniques are needed to make future exploration affordable.

Objectives include:

Development of propulsion concepts whose cost is less than 50% of currently available heavy-lift propulsion options but with similar performance (i.e., reduced parts count, increased robustness to allow less expensive manufacturing techniques, less complex parts to maximize vendor competition, maximization of common parts, etc.) - both solid and liquid options are desired.

Development and demonstration of low-cost manufacturing techniques (i.e., use of rapid prototype techniques for metallic parts, application of nano-technology for manufacturing of near net shape manufacturing, etc.).

### **X2.02 High Thrust In-Space Propulsion**

**Lead Center: GRC**

**Participating Center(s): JSC, MSFC**

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This solicitation intends to examine a range of key technology options associated with cryogenic, non-toxic storable, and solid core nuclear thermal propulsion (NTP) systems for use in future exploration missions. Non-toxic engine technology, including new mono and bi-propellants, is desired for use in lieu of the currently operational NTO/MMH engine technology. Handling and safety concerns with toxic chemical propellants can lead to more costly propulsion systems. For future short round trip missions to Mars, NTP systems using nuclear fission reactors may be enabling by helping to reduce launch mass to reasonable values and by also increasing the payload delivered for Mars exploration missions. Non-toxic and cryogenic engine technologies could range from pump fed or pressure fed reaction control engines of 25-1000 lbf up to 60,000 lbf primary propulsion engines. Pump fed NTP engines in the 15,000-25,000 lbf class, used individually or in clusters, would be used for primary propulsion.

Specific technologies of interest to meet proposed engine requirements include:

- Non-toxic bipropellant or monopropellants that meet performance targets (as indicated by high specific impulse and high specific impulse density) while improving safety and reducing handling operations as compared to current state-of-the-art storable propellants.
- High temperature, low burn-up carbide- and ceramic-metallic (cermet)-based nuclear fuels with improved coatings and /or claddings to maximize hydrogen propellant heating and to reduce fission product gas release into the engine's hydrogen exhaust stream.
- Low-mass propellant injectors that provide stable, uniform combustion over a wide range of propellant inlet temperature and pressure conditions.
- High temperature materials, coatings and/or ablatives or injectors, combustion chambers, nozzles, and nozzle extensions.
- High temperature and cryogenic radiation tolerant instrumentation and avionics for engine health monitoring. Non-invasive designs for measuring neutron flux (outside of reactor), chamber temperature, operating pressure, and liquid hydrogen propellant flow rates over wide range of temperatures are desired. Sensors need to operate for months/years instead of hours.
- Combustion chamber thermal control technologies such as regenerative, transpiration, swirl or other cooling methods, which offer improved performance and adequate chamber life.
- Long life, lightweight, reliable turbopump designs and technologies include seals, bearing and fluid system components. Hydrogen technologies are of particular interest.
- Highly-reliable, long-life, fast-acting propellant valves that tolerate long duration space mission environments with reduced volume, mass, and power requirements is also desirable.
- Radiation tolerant materials compatible with above engine subsystem applications and operating environments.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.04.

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## X2.03 Electric Propulsion Systems

Lead Center: GRC

Participating Center(s): JPL, MSFC

The goal of this subtopic is to develop innovative technologies for high-power (100 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions as well. Improved performance of propulsion systems that are integrated with associated power and thermal management systems and that exhibit minimal adverse spacecraft-thruster interaction effects are of interest. Innovations are sought that increase system efficiency, increase system and/or component life, increase system and/or component durability, reduce system and/or component mass, reduce system complexity, reduce development issues, or provide other definable benefits. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions. System efficiencies in excess of 50% and system lifetimes of at least 5 years (total impulse > 1 x 10<sup>7</sup> N-sec) are desired. Specific technologies of interest in addressing these challenges include:

- Long-life, high-current cathodes (100,000 hours).
- Electric propulsion designs employing alternate fuels (ISRU, more storable).
- Electrode thermal management technologies.
- Innovative plasma neutralization concepts.
- Metal propellant management systems and components, and cathodes.
- Low-mass, high-efficiency power electronics for RF and DC discharges.
- Lightweight, low-cost, high-efficiency power processing units (PPUs).
- PPUs that accept variable input voltages of greater than 200V and vary by a factor of 2-to-1.
- Direct drive power processing units.
- Low-voltage, high-temperature wire for electromagnets.
- High-temperature permanent magnets and/or electromagnets.
- Application of advanced materials for electrodes and wiring.
- Highly accurate propellant control devices/schemes.
- Miniature propellant flow meters.
- Lightweight, long-life storage systems for krypton and/or hydrogen.
- Fast-acting, very long-life valves and switches for pulsed inductive thrusters.
- Superconducting magnets.
- Lightweight thrust vector control for high-power thrusters.
- Fast-starting cathodes.

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- Propellantless cathodes.
  - High temperature electronics for power processing units.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.04.

### Life Support and Habitation Systems Topic X3

Life support and habitation encompasses the process technologies and equipment necessary to provide and maintain a livable environment within the pressurized cabin of crewed spacecraft. Functional areas of interest to this solicitation include thermal control and ventilation, atmosphere resource management and particulate control, water recovery systems, solid waste management, habitation systems, food production, environmental monitoring and fire protection systems. Technologies must be directed at long duration missions in microgravity, including earth orbit and planetary transit. Requirements include operation in microgravity and compatibility with cabin atmospheres of up to 34% oxygen by volume and pressures ranging from 1 atmosphere to as low as 7.6 psi (52.4 kPa). Special emphasis is placed on developing technologies that will fill existing gaps, reduce requirements for consumables and other resources including mass, power, volume and crew time, and which will increase safety and reliability with respect to the state-of-the-art. Non-venting processes may be of interest for technologies that have future applicability to planetary protection. Technology solutions involving both physicochemical and biological approaches are sought. Results of a Phase I contract should demonstrate proof of concept and feasibility of the technical approach. A resulting Phase II contract should lead to development, evaluation and delivery of prototype hardware. Specific technologies of interest to this solicitation are addressed in each subtopic.

Sub Topics:

#### **X3.01 Enabling Technologies for Biological Life Support**

**Lead Center:** KSC

**Participating Center(s):** ARC, JSC, MSFC

##### **Biochemical Systems for CO<sub>2</sub> Removal and Processing to Useful Products**

NASA is interested in biochemical or biological systems and supporting hardware suitable for purifying the atmosphere in confined spaces such as crewed spacecraft or space habitat cabins. Of special interest is the removal and fixation of CO<sub>2</sub> from a cabin atmosphere via biochemical pathways or autotrophic organisms (plants, algae, cyanobacteria, etc) to produce oxygen and other useful products, including food. Processes considering photosynthesis must address how quantum and/or radiation use efficiency will be improved. Systems should consider minimizing power, mass, consumables and biologically produced waste, while maximizing reliability and efficiency.

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## **Biochemical Systems for Wastewater Treatment**

NASA is interested in biological or biochemical approaches to assist in purifying and recycling wastewater in confined spaces such as crewed spacecraft or space habitat cabins. Of special interest are novel approaches for removing carbon, nitrogen and phosphorus to potable or near potable concentrations, and reduction of biosolids. Systems should consider operating with low power, low consumables, low volume, high reliability and rapid deployment, as well as addressing multi-phase flow issues for reduced gravity.

### **X3.02 Crew Accommodations and Waste Processing for Long Duration Missions**

**Lead Center:** ARC

**Participating Center(s):** GRC, JSC, KSC, MSFC

Critical gaps exist with respect to interfaces between human accommodations and life support systems for long duration human missions beyond low Earth orbit. New technologies are needed for management and processing of human fecal waste and for clothing and laundry. Proposals should explicitly describe the weight, power, volume, and microgravity performance advantages.

#### **Human Fecal Waste Management**

Microgravity technology is needed to collect, stabilize, safely, recover useful materials, and store human feces or its processed residuals. Simple low energy systems that recover water and sterilize/sanitize feces or mineralize it to minimal residuals (and perhaps gases or fuels) are desired. Complete systems are desired that include consideration of preprocessing, processing, and venting or containment for storage of the resultant residuals and/or recovered materials.

#### **Clothing and Laundry Systems**

The requirements for crew clothing are balanced between appearance, comfort, wear, flammability and toxicity. Ideally, crew clothing should have durable flame resistance in a 34% O<sub>2</sub> (by volume) enriched environment. Fabrics must enable multiple crew wear cycles before cleaning/disposal.

The laundry system should remove or stabilize the combined contamination from perspiration salts, organics, dander and dust, preserve flame resistance properties, and use cleaning agents compatible with water recovery technologies, including both physiochemical and biological processes. Proposals using water for cleaning should use significantly less than 10 kg of water per kg of clothing cleaned.

### **X3.03 Environmental Monitoring and Fire Protection for Spacecraft Autonomy**

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**Lead Center:** JPL

**Participating Center(s):** ARC, GRC, JSC, KSC, MSFC

### **Environmental Monitoring**

Monitoring technologies to ensure that the chemical and microbial content of the air and water environment of the crew habitat falls within acceptable limits, and life support system is functioning properly and efficiently, are sought. Required technology characteristics: 2-year shelf-life; functionality in microgravity, low pressure and elevated oxygen cabin environments. Significant improvements in miniaturization, operational reliability, life-time, self-calibration, and reduction of expendables should be demonstrated. Proposals should focus on one of the following areas:

- Process control monitors for life support. Improved reliability for closed-loop feedback control system.
- Trace toxic metals, trace organics in water.
- Monitoring trace contaminants in both air and water with one instrument.
- Microbial monitoring for water and surfaces using minimal consumables.
- Optimal system control methods. Operate the life support system with optimal efficiency and reliability, using a carefully chosen suite of feedback and health monitors, and the associated control system.
- Sensor suites. Determine, with robust technical analysis, the optimal number and location of sensors for the information that is needed, and efficient extraction of data from the suite of sensors.

### **Fire Protection**

Spacecraft fire protection technologies to detect the overheating or combustion of spacecraft materials by their particulate and/or gaseous signatures are also sought. These must be of suitable size, mass, and volume for a distributed sensor array. Technologies that detect smoke particulates and identify characteristics (mean particulate sizes or distribution) would also be useful. Catalytic or sorbent technologies suitable for the rapid removal of gases, especially CO, and particulate during a contingency response are desired.

## **X3.04 Spacecraft Cabin Ventilation and Thermal Control**

**Lead Center:** JSC

**Participating Center(s):** GRC, GSFC, JPL, LaRC, MSFC

Future spacecraft will require quieter fans, better cabin air filtration, and advanced active thermal control systems.

### **Small Fan Aero-Acoustics**

Procedures and non-intrusive apparatus to measure the sound pressure levels in the inlet and exhaust duct of a candidate spacecraft ventilation fan are requested. Details of the aerodynamic design and the predicted aerodynamic performance of the candidate spacecraft cabin ventilation fan are reported in NASA



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CR-2010-216329, "Aerodynamic Design and Computational Analysis of a Spacecraft Cabin Ventilation Fan". The duct diameter for this fan (89 mm) falls below the minimum diameter required (150 mm) by ASHRAE Standard 68. The pressure rise at design point for this fan (925 Pa) exceeds the maximum recommended (750 Pa) in ISO 10302. The procedure that is requested to be developed should apply to fans of similar size and capacity (or greater) as the identified candidate spacecraft ventilation fan. The procedure developed should overcome the deficiencies in the standards by providing plots of overall sound power levels as a function of fan flow rate (from full flow to fully throttled conditions) along lines of constant fan rotational speed in the inlet and exhaust ducts. Values of the radial and circumferential duct mode sound power levels calculated from the pressure measurement should be recorded and made available for subsequent examination at all tested conditions. It also must be shown that the flow-induced microphone self-noise, if any, does not contribute significantly to the measured fan sound pressure levels or sound power levels. Validation of the measured fan sound power levels must be shown for a sub-set of the performance range using an alternate technique.

### **Methods of Particulate Separation and Filtration from Air**

Methods of particulate air filtration and/or separation targeting a range of particle sizes from tens of micron down to submicron in conjunction with efficient methods of regeneration are sought. The proposed technical solutions should reduce crew maintenance time and eliminate the need for consumable filter elements. These units should be able to handle large surges of particles and operate over very long periods. They should also be self-cleaning in-place (preferable) or off-line. Targeted technologies should be compact and lightweight, easily integrated with the spacecraft life support system, and provide viable methods for disposing of collected particulate matter while minimizing or eliminating direct contact by the crew.

### **Active Thermal Control Systems**

Thermal control systems will be required that can dissipate a wide range of heat loads with widely varying environments while using fewer of the limited spacecraft mass, volume and power resources. The thermal control system designs must accommodate high input heat fluxes at the heat acquisition source and harsh thermal environments at the heat rejection sink. Advances are sought for microgravity thermal control in the areas of:

- Innovative Thermal Components and System Architectures that are capable of operating over a wide range of heat loads in varying environments (for example, a 10:1 heat load range in environments ranging from 0 to 275K).
- Two-phase Heat Transfer Components and System Architectures for nuclear propulsion that will allow the acquisition, transport, and rejection of waste heat on the order of megawatts,.
- Heat rejection hardware for transient, cyclical applications using either phase change material heat exchangers or efficient evaporative heat sinks.
- Smaller, lighter high performance heat exchangers and coldplates.
- Low temperature external working fluids (a temperature limit of less than 150K with favorable thermophysical properties - e. g., viscosity and specific heat).
- Internal working fluids that are non-toxic, have favorable thermophysical properties, and are compatible with aluminum tubing (i.e., no corrosion for up to 10 years).
- Low mass, high conductance ratio thermal switches.
- Long-life, lightweight, efficient single-phase thermal control loop pumps capable of producing relatively high-pressure head (~4 atm).

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- Dust tolerant long-life radiators.
  - Variable area radiators (e. g., variable capacity heat pipe radiators or drainable radiators).
  - Radiators compatible with inflatable volumes.
  - Thermal systems and/or components to extend operational times for spacecraft under the extreme planetary environments, for example: the Venusian surface at approximately 460C and 98 atm.
  - Flexible heat pipes.
  - Methods to predict the performance of cryogenic multi-layer insulation blankets at 1 atmosphere and during ascent venting.
  - Advanced thermal analysis tools that utilize stream processing to improve computational speed over conventional approaches. Possible candidates are: view factor calculation via ray tracing, orbital heating rate calculations, and thermal environment modeling.
  - Inflatable/deployable shades to enhance reduce boiloff of cryogenic propellants in long-term storage in low earth orbit.

#### Extra-Vehicular Activity Technology Topic X4

Advanced Extra -Vehicular Activity (EVA) systems are necessary for the successful support of the International Space Station (ISS) beyond 2020 and future human space exploration missions for in-space microgravity EVA and for planetary surface exploration. Advanced EVA systems include the space suit pressure garment, airlocks, the Portable Life Support System (PLSS), Avionics and Displays, and EVA Integrated Systems. Future human space exploration missions will require innovative approaches for maximizing human productivity and for providing the capability to perform useful tasks safely, such as assembling and servicing large in-space systems and exploring surfaces of the Moon, Mars, and small bodies. Top-level requirements include reduction of system weight and volume, low or non-consuming systems, increased hardware reliability, durability, operating life, increased human comfort, and less restrictive work performance in the space environment. All proposed Phase I research must lead to specific Phase II experimental development that could be integrated into a functional EVA system.

Sub Topics:

##### **X4.01 Space Suit Pressure Garment and Airlock Technologies**

**Lead Center:** JSC

**Participating Center(s):** GRC

Advanced space suit pressure garment and airlock technologies are necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations.

Research is needed in the following space suit pressure garment areas:

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- The space suit pressure garment requires innovative technologies that increase the life, comfort, mobility, and durability of gloves, self sealing materials to minimize the effects of small punctures or tears, and materials that are resistant to abrasion.
  - Innovative garments that provide direct thermal control to crew member that minimize consumables are needed as well as materials for helmets that are scratch resistant or prevent fogging
  - Technologies for space suit flexible thermal insulation suitable for use in vacuum and low ambient pressure are also needed.
  - Light Weight Bearings for use in mobility joints in the pressure garment are needed.
  - Advanced cooling garments that are highly efficient in removing metabolic heat and are low power consuming are needed.
  - Advanced suit materials that provide radiation protection and reduce risks associated with electrical charging and shock.

Due to the expected large number of space walks that will be performed on the ISS beyond 2020 and future human space exploration missions, innovative technologies and designs for both microgravity and surface airlocks will also be needed.

Research is needed in the following space suit airlock area:

Technology development is needed for minimum gas loss airlocks providing quick exit and entry that can accommodate an incapacitated crew member, suit port/suit lock systems for docking a space suit to a dust mitigating entry/hatch in order for the space suit to remain in the airlock and prevent dust from entering the habitable environment.

#### **X4.02 Space Suit Life Support Systems**

**Lead Center:** JSC

**Participating Center(s):** GRC

Advanced space suit life support systems are necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations. Exploration missions will require a robust, lightweight, and maintainable Primary Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation and CO<sub>2</sub> removal, and a thermal control system for crew member metabolic heat rejection. Innovative technologies are needed for high-pressure O<sub>2</sub> delivery, crewmember cooling, heat rejection, and removal of expired CO<sub>2</sub> and water vapor.

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Focused research is needed in the following space suit life support system areas:

Feedwater Supply Bladder for PLSS - Focused research is needed to develop a shallow, translucent water bladder that will serve to pressurize the water loop for the new PLSS by using the suit pressure to compress the flexible bladder material. The unique aspect of this bladder includes a detection system to indicate via a signal that the remaining usable feed water is approximately .5 kg. Some additional requirements are: Usable capacity => 4.5 kg, Chemically inert to avoid chemical reactions with the feed water which may be DI water to potable standards, Approximate shape is a semi-circle with a diameter of 16 in (40.6 cm), Configuration is similar to an accumulator with a single inlet, 1/8in hose barb, and the Maximum Allowable Working Pressure => 20 psid (138 kPa differential).

PPCO<sub>2</sub>-H<sub>2</sub>O-O<sub>2</sub> Sensor for PLSS - Focused research is needed for a PLSS sensor that is able to measure critical life support constituents in a single combined flow-through sensor configuration. Free water tolerance is an important feature. Test and Shuttle/ISS space suit experience has shown this to be a real possibility that the sensor should tolerate.

#### **X4.03 Space Suit Radio, Sensors, Displays, Cameras, and Audio**

**Lead Center:** GRC

**Participating Center(s):** JSC

Future EVAs need advances in radio technologies, including antennas, tunable RF front-ends, and power amplifiers; low-power cameras; more accurate, reliable, and packaged core temperature, CO<sub>2</sub>, and biomedical sensors; user-friendly, minimally invasive crewmember information displays; and technologies that provide improvements in speech quality, listening quality and listening effort for in-helmet aural and vocal communications. Progress in these technologies will help ensure reliable communications, crew safety and comfort, and work efficiency and autonomy. The focus of this subtopic is to advance future EVA lightweight, compact, low-power technologies in five primary areas: radios, sensors, displays, cameras, and suit audio. The expectation for all of these EVA areas is that a report demonstrating the concept, requirements, design, and technical feasibility will be delivered at the end of Phase I, and that a working and fully functional device will be delivered at the end of Phase II.

The next-generation EVA radio needs to fulfill multiple functions while satisfying stringent requirements on size, weight and power (SWaP) consumption in the ISM S-band (2.4 - 2.483 GHz) and Ka-band (approximately 26 GHz). Ideally, eventual radio SwAP reductions would result in approximately 115 cubic inches, 3.5 - 5.5 pounds, and 15 watts total power consumption, respectively. Next-generation EVA radios will need to support multiple comm loops and point-to-point EVA comm., receive caution and warning messages from the vehicle and other EVA crew, receive, store, and display voice/text messaging to handle comm delays. Moreover, next-generation EVA antenna systems that effectively present uniform coverage around the suit are needed. Likewise, the next-generation EVA radio needs RF front-end architectures capable of presenting baseband or IF signals to waveform processing hardware in multiple bands. Radiation-hardened-by-design transceiver technologies improving upon current Single Event Upset tolerant approaches, along with cognitive technologies, are needed for future EVA exploration to Near Earth Asteroids and beyond.

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In addition, advances in tunable technology that permit high Q factor, minimum insertion losses, and excellent linearity are desirable at the given S- and Ka-band Gigahertz frequencies for agility. The next-generation EVA radios will need to support voice, telemetry, and standard/high definition video data flows (up to 20 Mbps); ensure rapid upgrades via scalable, open, and modular architectures; and, advance power aware technologies to optimize efficiency, conserve EVA battery lifetime power, and prolong duration of EVA operations. Finally, no matter what type of transceiver architecture is used in the next-generation EVA radio, the power amplifier is always a key component to enable new functionality, and to minimize the power consumption of the whole radio. Current amplifiers suffer from one or many of the following drawbacks: a) insufficient power added efficiency, b) insufficient linearity performance and incompatibility with modern modulation signals, and c) incompatible with silicon CMOS technology. Most of the commercial PAs are based on III-V GaAs material system, which is more expensive compared to the CMOS fabrication processes. Additionally, the incompatibility with silicon CMOS technology makes it impossible to realize a fully integrated radio-on-a-chip system. Consequently, the implemented radio with the existing power amplifiers requires much more SwAP and higher fabrication costs. Advances are needed in the efficiency and linearity of power amplifiers for next-generation EVA radio applications.

Crew health and suit monitoring require advancement of lightweight CO<sub>2</sub>, biomedical (heart rate, blood OX, EKG) and core temperature sensors with reduced size, increased reliability, and greater packaging flexibility. Consequently, technologies are needed to provide high accuracy, low mass, and low-power sensors that measure flow rate, pressure, temperature, and relative humidity or dew point. All sensors must operate in a low pressure 100% O<sub>2</sub> environment with high humidity and may be exposed to liquid condensate.

Because missions must be designed with appropriate radiation shielding and adjusted to keep the radiation doses within tolerable limits, real-time, accurate, instantaneous and integrated radiation dose measurements and readout are needed such as novel dosimeter sensors. Given sufficient warning, astronauts can move to a more shielded part of the space vehicle and lessen dose impact. As cosmic rays impinge upon the vehicle leaving the magnetosphere, sensors are needed to determine the type of radiation and dose as well as reduce the potential risk of biological tissue damage.

Future EVAs need a user-friendly and minimally invasive crewmember information display device that provides significant task efficiency improvement for a broad range of EVA tasks. Current Head-Mounted Display and Near-to-Eye display technologies are a non-starter for EVA, because the display must be mechanically decoupled from the user's head in order to improve crew safety, comfort, and prevent display misalignment. This in turn makes for more difficult specifications for the eyebox (tolerance to misalignment before image goes out of focus), field of view (angle of the image created by the optics), and eye relief (working distance from the eye to the last optical element). Additionally, current Helmet-Mounted Display technologies are challenged in EVA applications due to geometric constraints within the helmet, and future display technologies must ensure suit displays can operate outside the suit protection in thermal, radiation, and vacuum environments as well as internally without imposing ignition hazards due to 100% oxygen environment. Key performance parameters (targets) include: Graphical Data Presentation: SXGA @ 40 deg FOV (possibly biocular); Decoupled from User's Head - Large Eyebox: 100 mm x 100mm x 50mm (D); Sunlight Readability: 500 fL inside visor, 1800 fL outside visor (>10 to 1 contrast).

Future EVAs need to support high definition motion and high resolution imagery with ultra compact, low-power HD cameras and low loss compressed digital data output for RF transmissions and/or IP networks. Hemispherical and dynamic cameras are desired, where hemispherical cameras take video views of a crewmember (360 degrees), distorting those views thru optics and then undistorting those views via software on the ground to pan/zoom for total situational awareness. Dynamic cameras can take stills and motion in variable bandwidths, capture image based on link quality, change frame rates, interfaced to gigabit Ethernet and in a rad-tolerant package with dynamically reconfigure compression core(s) and common 'back-end' interfaces.

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The space suit environment presents a unique challenge for capturing and transmitting speech communications to and from a crewmember. The in-suit acoustic environment is characterized by highly reflective surfaces, causing high levels of reverberation, as well as spacesuit-unique noise fields; and wide swings of static pressure levels. Due to these factors, the quality of speech delivered to and from the inside of a spacesuit helmet can be low and can have a negative effect on inbound and outbound speech intelligibility. The traditional approach to overcome the challenges of the spacesuit acoustic environment is to use a skullcap-based system of microphones and speakers. Cap-based systems are less successful, however, in attenuating high noise levels generated outside the spacesuit, and many logistical issues exist for head-mounted caps (e.g., crewmembers are not able to adjust the skullcap, headset or microphone booms during EVA operations, interference between the protuberances of the cap and other devices, comfort, hygiene, proper positioning and dislocation, and wire fatigue and blind mating of the connectors, multiple cap sizes to accommodate anthropometric variations in crew heads).

NASA is seeking technologies in support of improvements in speech intelligibility, speech quality, listening quality and listening effort for in-helmet aural and vocal communications. The specific focus of this SBIR subtopic is on improving the interface between crewmember and the acoustic pickup (microphones) and generation (speaker) systems. Devices are sought to improve or resolve acoustic, physical and technical problems (listed above) that have been associated with skullcap-mounted speakers and microphones, or allow for the elimination of skullcap-mounted speakers and microphones. In particular, voice communications systems are sought that have provided crewmembers with adequate speech intelligibility over background noise within, and external to, the spacesuit. Overall system performance must provide Mean Opinion Score (MOS) for Listening Quality (Lq) and Listening Effort (Le) of 3.9 or greater, or Articulation Index (AI) of .7 or better or 90% Intelligibility in the crewmember's native language for both inbound and outbound speech communication. Specific technologies of interest include, but are not limited to: acoustic modeling of the in-suit acoustic environment, including the ability to model structure-borne vibration in helmet and suit structures as well as transduction to and from the acoustic medium; low-mass, low-volume, low-distortion, space-qualified speakers with low variation in sensitivity with static pressure. Changes in speaker sensitivity should be less than 2 dB over the speech band with changes in static pressure between 3 and 18 psia; low-mass, ultra-low-volume (

## Lightweight Spacecraft Materials and Structures Topic X5

The SBIR topic area of Lightweight Spacecraft Materials and Structures centers on developing lightweight inflatable structures, advanced manufacturing technologies for metallic and composite materials, structural sensing techniques, and in-situ non-destructive evaluation systems. Applications are expected to include space exploration vehicles including launch vehicles, crewed vehicles, and surface and habitat systems. The area of expandable structures solicits innovative concepts to support the development of lightweight-structure technologies that would be viable solutions to high packaging efficiency and increasing the usable primary pressurized volume in habitats, airlocks, and other crewed vessels. Technologies are needed to minimize launch mass, size and costs, while maintaining the required structural performance for loads and environments. Advanced fabrication and manufacturing of lightweight structures focuses on the development of metallic alloys and hybrid materials, processing and fabrication technologies related to near-net shape forming. The goal is to reduce structural weight, assembly steps, and minimize welds, resulting in increased reliability and reduced cost. Research should evaluate material compatibility with forming methods and establish fundamental microstructure/processing/property

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correlations to guide full-scale fabrication. Laboratory scale test methods are needed to accurately simulate the deformation modes experienced in large-scale manufacturing. Polymer matrix composite (PMC) materials have been identified as a critical need for launch and in-space vehicles. The reduction of structural mass translates directly to additional performance, increased payload mass and reduced cost. PMC materials are also critical for other structures, such as cryogenic propellant tanks. Advances in PMC materials, automated manufacturing processes, non-autoclave curing methods, advances in damage-tolerant/repairable structures, and PMC materials with high resistance to microcracking at cryogenic temperatures are sought. The objective is to advance technology readiness levels of PMC materials and manufacturing for launch vehicle and in-space applications resulting in structures having affordable, reliable, and predictable performance. Practical modular structural sensor systems and NDE technologies are sought for spaceflight missions. Smart, lightweight, low-volume, and stand-alone sensor systems should reduce the complexities of standard wires and connectors and enable sensing in locations not normally accessible. NDE sensor system technology should include modular, low-volume systems and have the ability to perform inspections with minimal human interaction. Systems need to provide the location and extent of damage with the minimal data transfer between the flight system and Earth. Mission application areas include space transportation vehicles, pressure vessels, ISS modules, inflatable structures, EVA suits, MMOD shields, and thermal protection structures. Research under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Sub Topics:

### **X5.01 Expandable Structures**

**Lead Center:** LaRC

**Participating Center(s):** JSC

The SBIR subtopic area of Lightweight Inflatable Structures solicits innovative concepts to support the development of primary pressurized expandable habitat and storage modules for space exploration environments. Inflatable concepts should illustrate small efficient launch volumes and large deployment volumes. Concepts should also illustrate simple designs, efficient deployment techniques, lightweight materials, and potential for integrated hard points. Robustness, damage tolerance, and minor repair capabilities should also be considered in concept submittals. Airlock and window integration into the inflatable should also be considered.

Lightweight secondary structures for internal outfitting of the inflatable structure after deployment are also solicited. Lightweight concepts of interest include walkways, storage facilities, and hard points for utility or operational subsystems. Secondary structures should be packing and mass efficient, stiff-post deployment, redundant, modular, and multi-functional.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of a Phase II contract.

### **X5.02 Advanced Fabrication and Manufacturing of Metallic and Polymer Matrix Composite Materials for Lightweight Structures**

**Lead Center:** LaRC

**Participating Center(s):** GRC, KSC, MSFC

The objective of the subtopic is to advance technology readiness levels of lightweight structures for launch vehicles and in-space applications, by using advanced materials and manufacturing techniques, resulting in structures

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having affordable, reliable, predictable performance with reduced costs. Performance metrics include: achieving adequate structural and weight performance; manufacturing and life cycle affordability analysis; verifiable practices for scale-up; validation of confidence in design, materials performance, and manufacturing processes; and quantitative risk reduction capability. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable materials/manufacturing technology combinations that can be scaled up for very large structures.

Materials topics should focus on lightweight monolithic metallic materials or Polymer Matrix Composites (PMC) that, in combination with design modifications, can significantly reduce structural mass. Research should include assessment of the material response to forming and joining methods and verification of post-forming properties. Also of interest are high temperature PMC materials for high performance composite structures (high temperature applications), particularly those which are compatible with current composite manufacturing techniques. High temperature PMCs should enable reduction of vehicle mass through elimination or reduction of thermal protection systems. Another area of interest covers development of lightweight damage-tolerant materials that are compatible with forming methods that can significantly reduce structural mass. Proposals to each area will be considered separately.

Fabrication technology topics should focus on near-net-shape and automated manufacturing methods, which can reduce structural weight, processing, and assembly steps, and minimize joints, resulting in increased reliability and reduced cost, and characterization of material response to forming and joining methods. Other interests include development of laboratory scale test methods to accurately simulate large scale manufacturing for use in screening material behavior. Research should include computational modeling and simulation of material behavior and testing to characterize material properties and validate manufacturing methods.

### **X5.03 Spaceflight Structural Sensor Systems and NDE**

**Lead Center:** LaRC

**Participating Center(s):** JSC, MSFC

There is a growing use for modular/low mass-volume, low power, low maintenance systems, that reduce or eliminate wiring, stand-alone smart sensor systems that provide answers as close to the sensor as practical and systems that are flexible in their applicability. The systems should allow for additions or changes in instrumentation late in the design/development process and enable relocation or upgrade on orbit. They reduce the complexities of standard wires and connectors and enable sensing functions in locations not normally accessible with previous technologies. They allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles and payloads supporting NASA missions.

There is also a need for modular/low mass/volume smart NDE sensors systems and associated software that enable effective use with minimum crew training or re-familiarization after extended periods of no use. Systems should include ability to perform inspections with minimal human interaction. These systems need to provide reliable assessments of the location and extent of damage with the minimal data transfer between vehicle and Earth. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments. Many applications require the ability to see through conductive and/or thermal insulating materials without contacting the surface. Sensors that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on



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the structure. Structural design and material configurations are sought that can enhance NDE and monitoring. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who may only use the NDE tool infrequently.

## Autonomous Systems and Avionics Topic X6

NASA invests in the development of autonomy and automation software, advanced avionics, integrated system health management, and robust software technology capabilities for the purpose of enabling complex missions and technology demonstrations. The software and avionics elements requested within this topic are critical to enhancing flight system functionality, reducing system vulnerability to extreme radiation and thermal environments, reducing system risk, and increasing autonomy and system reliability through processes, operations, and system management. As a game-changing and cross-cutting technology area, autonomous software and avionics are applicable to broad areas of technology emphasis, including heavy lift launch vehicle technologies, robotic precursor platforms, utilization of the International Space Station, and spacecraft technology demonstrations performed to enable long duration space missions. All of these flight applications will require unique advances in software technologies and avionics such as integrated systems health management, autonomous systems for the crew and mission operations, radiation hardened, multi-core processors, and reliable, dependable software. The exploration of space requires the best of the nation's technical community to step up to providing the technologies, engineering, and systems to explore the beyond LEO, visit asteroids and the Moon, and to extend our reach to Mars.

Sub Topics:

### **X6.01 Spacecraft Autonomy and Space Mission Automation**

**Lead Center:** ARC

**Participating Center(s):** JPL, JSC

Future human spaceflight missions will place crews at large distances and light-time delays from Earth, requiring novel capabilities for crews and ground to manage spacecraft consumables such as power, water, propellant and life support systems to prevent Loss of Mission (LOM) or Loss of Crew (LOC). This capability is necessary to handle events such as leaks or failures leading to unexpected expenditure of consumables coupled with lack of communications. If crews in the spacecraft must manage, plan and operate much of the mission themselves, NASA must migrate operations functionality from the flight control room to the vehicle for use by the crew. Migrating flight controller tools and procedures to the crew on-board the spacecraft would, even if technically possible, overburden the crew. Enabling these same monitoring, tracking, and management capabilities on-board the spacecraft for a small crew to use will require significant automation and decision support software. Required capabilities to enable future human spaceflight to distant destinations include:

- Enable on-board crew management of vehicle consumables that are currently flight controller responsibilities.

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- Increase the onboard capability to detect and respond to unexpected consumables-management related events and faults without dependence on ground.
  - Reduce up-front and recurring software costs to produce flight-critical software.
  - Provide more efficient and cost effective ground based operations through automation of consumables management processes, and up-front and recurring mission operations software costs.

The same capabilities for enabling human spaceflight missions are directly applicable to efforts to automate the operation of unmanned aircraft flying in the National Airspace (NAS) and robotic planetary explorers.

### **Mission Operations Automation**

Peer-to-peer mission operations planning

Mixed initiative planning systems

Elicitation of mission planning constraints and preferences

Planning system software integration

### **Space Vehicle Automation**

Autonomous rendezvous and docking software

Integrated discrete and continuous control software

Long-duration high-reliability autonomous system

Power aware computing

### **Robotic Systems Automation**

Mutli-agent autonomous systems for mapping

Uncertainty management for mapping system

Uncertainty management for grasping robotic system

Uncertainty management for path planning and traversing

Emphasis of proposed efforts:

- Software proposals only, but emphasize hardware and operating systems the proposed software will run on (e.g., processors, sensors).

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- In-space or Terrestrial applications (e.g., UAV mission management) are acceptable.
  - Proposals must demonstrate mission operations cost reduction by use of standards, open source software, staff reduction, and/or decrease of software integration costs.
  - Proposals must demonstrate autonomy software cost reduction by use of standards, demonstration of capability especially on long-duration missions, system integration, and/or open source software.

## **X6.02 Radiation Hardened/Tolerant and Low Temperature Electronics and Processors**

**Lead Center: MSFC**

**Participating Center(s): GSFC, JPL**

Exploration flight projects, robotic precursors, and technology demonstrators that are designed to operate beyond low-earth orbit require avionic systems, components, and controllers that are capable of enduring the extreme temperature and radiation environments of deep space, the lunar surface, and eventually the Martian surface.

Spacecraft vehicle electronics will be required to operate across a wide temperature range and must be capable of enduring frequent (and often rapid) thermal-cycling. Packaging for these electronics must be able to accommodate the mechanical stress and fatigue associated with the thermal cycling. Spacecraft vehicle electronics must be radiation hardened for the target environment. They must be capable of operating through a minimum total ionizing dose (TID) of 300 krad (Si), provide fewer Single Event Upsets (SEUs) than 10-10 to 10-11 errors/bit-day, and provide single event latchup (SEL) immunity at linear energy transfer (LET) levels of 100 MeV cm<sup>2</sup>/mg (Si) or more. All three characteristics for radiation hardened electronics of TID, SEU and SEL are needed. Electronics hardened for thermal cycling and extreme temperature ranges should perform beyond the standard military specification range of -55°C to 125°C, running as low as -230°C or as high as 350°C.

Considering these target environment performance parameters for thermal and radiation extremes, proposals are sought in the following specific areas:

- Low power, high efficiency, radiation-hardened processor technologies.
- Technologies and techniques for environmentally hardened Field Programmable Gate Array (FPGA).
- Innovative radiation hardened volatile and nonvolatile memory technologies.
- Tightly-integrated electronic sensor and actuator modules that include power, command and control, and processing.
- Radiation hardened analog application specific integrated circuits (ASICs) for spacecraft power management and other applications.
- Radiation hardened DC-to-DC converters and point-of-load power distribution circuits.
- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for

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low-temperature and wide-temperature electronic systems and components.

- Physics-based device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom mixed-signal and analog circuits.
- Circuit design and layout methodologies/techniques that facilitate improved radiation hardness and low-temperature (-230°C) analog and mixed-signal circuit performance.
- Packaging capable of surviving numerous thermal cycles and tolerant of the extreme temperatures on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.

### **X6.03 Integrated System Health Management for Flexible Exploration**

**Lead Center: ARC**

**Participating Center(s): JPL, JSC, KSC, MSFC**

Novel integrated system health management technologies will enable NASA's pursuit of a more sustainable and affordable approach to spaceflight. New heavy lift launch systems will incorporate new engines, propellants, materials, and combustion processes and will increase NASA's capabilities and significantly lower operations costs. Health management is essential for the safe and reliable operation of these complex systems. Innovative health management technologies are also essential for long-duration robotic precursor missions. Projects may focus on one or more relevant subsystems such as rocket engines, liquid propulsion systems, structures and mechanisms, thermal protection systems, power, avionics, life support, communications, and software. Specific technical areas of interest are methods and tools for:

- Early-stage design of health management functionality during the development of space systems, including failure detection methods, sensor types and locations that enable fault detection to line replaceable units.
- Sensor validation and robust state estimation in the presence of inherently unreliable sensors. Focus on data analysis and interpretation using legacy sensors.
- Model-based fault detection and isolation based on existing sensor suites that enables fault detection within time ranges to allow mission abort.
- Automatic construction of models used in model-based diagnostic strategies, limiting model construction times to 60% of the time required using manual methods.
- Prognostic techniques able to anticipate system degradation before loss of critical functions and enable further improvements in mission success probability, operational effectiveness, and automated recovery of function.
- Techniques that address the particular constraints of maintaining long-duration systems health of structures, mechanical parts, electronics, and software systems are also of interest.

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## Human-Robotic Systems Topic X7

This call for technology development is in direct support of the Exploration Systems Mission Directorate (ESMD). The purpose of this research is to develop component and subsystem level technologies to support robotic precursor exploration missions. To that end, it is the intent of this Topic to capitalize on advanced technologies that allow humans and robots to interact seamlessly and significantly increase their efficiency and productivity in space. The objective is to produce new technologies that will reduce the total mass-volume-power of equipment and materials required to support both short and long duration planetary missions. The proposals must focus on component and subsystem level technologies in order to maximize the return from current SBIR funding levels and timelines. Doing so increases the likelihood of successfully producing a technology that can be readily infused into existing robotic system designs. This research focuses on technology development for the critical functions that will ultimately enable surface exploration for the advancement of scientific research. Surface exploration begins with short duration missions to establish a foundation, which leads to extensible functional capabilities. Successive buildup missions establish a continuous operational platform from which to conduct scientific research while on the planetary surface. Reducing risk and ensuring mission success depends on the coordinated interaction of many functional surface systems including power, communications infrastructure, and mobility and ground operations. This topic addresses technology needs within three subtopic areas:

- Mobility systems.
- Dexterous manipulation.
- The interfaces that facilitate productive and seamless interaction between humans and robots.

### Sub Topics:

#### **X7.01 Human Robotic Systems - Human Robot Interfaces**

**Lead Center:** ARC

**Participating Center(s):** JPL, JSC

The objective of this subtopic is to create human-robot interfaces that improve the human exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans. Ground controllers and astronauts will remotely operate robots using a range of control modes, over multiple distances (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

This subtopic seeks to develop new technologies that enable crew and ground controllers to better operate, monitor and supervise semi-autonomous robots. Of particular interest is software that improves robot operator productivity, situational awareness, and effectiveness.

Proposals are sought that address the following technology needs:

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- Crew telerobotic interfaces. User interfaces that enable crew to remotely operate and monitor robots from inside a flight vehicle, habitat and/or during an extra-vehicular activity (EVA). User interfaces must be appropriate and relevant for use with near-term flight systems.
  - Robot performance monitoring software. Software tools that enable remote monitoring of robot performance, detection of anomalies and contingencies, assessment of robot utilization and situational awareness of remote robot operations.
  - Robot tactical planning software. Software tools that enable efficient, rapid handling of contingencies during robot tactical operations. This may involve a combination of embedded and user interface modules.
  - Robot ground data systems. Systems and software for robot command planning and sequencing, telemetry processing, sensor/instrument data management, and automating ground control functions.

This subtopic does not solicit proposals for direct teloperation (e.g., joystick-based rate control), telepresence, or immersive virtual reality subsystems or systems.

## **X7.02 Human-Robotic Systems - Mobility Subsystems**

**Lead Center:** JSC

**Participating Center(s):** ARC, JPL

The objective of this subtopic is to create human-robotic technologies (hardware and software) to improve the exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans.

Ground controllers and astronauts will remotely operate robots using a range of control modes (teleoperation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

Proposals are sought that address the following technology needs:

- Subsystems to improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, in-space; and improve handling and maintenance of payloads and assets. This includes hazard detection sensors/perception, active suspension, grapple/anchoring, legged locomotion, robot navigation, and infrastructure-free localization. As well as, tactile sensors, human-safe actuation, active structures, dexterous grasping, modular "plug and play" mechanisms for deployment and setup, small/lightweight excavation/drilling devices to enable subsurface access, and novel manipulation methods.

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## High-Efficiency Space Power Systems Topic X8

This topic solicits technology development for high-efficiency power systems to be used for the human exploration of space. Technologies applicable to both space exploration and clean and renewable energy for terrestrial applications are of particular importance. Power system needs include: electric energy generation and storage for human-rated vehicles, electrical energy generation for in-space propulsion systems, and electric energy generation, storage, and transmission for planetary and lunar surface applications. Technology development is sought in: Fuel cells and electrolyzers including both proton exchange membrane and solid oxide technologies; Battery technology including components for improved performance and safety; Nuclear power systems including fission and radioisotope power generation; Photovoltaic power generation including solar cell, blanket and array technology; reliable, radiation tolerant electronic devices; and robust high voltage electronics.

Sub Topics:

### **X8.01 Fuel Cells and Electrolyzers**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC

Advanced primary fuel cell and regenerative fuel cell energy storage systems are enabling for various aspects of future Exploration missions. Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

#### **Proton Exchange Membrane (PEM) Fuel Cells and Electrolyzers**

Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

#### **Oxidation Resistant Gas Diffusion Layer (GDL)**

GDLs are integral to PEM fuel cell membrane-electrode-assemblies (MEAs). Traditional carbon or graphite based GDLs are very susceptible to oxidation under certain operating conditions in the pure oxygen environment of space fuel cell systems. This results in MEA degradation and shortened life. Proposals addressing the development of oxidation resistant GDLs that remain stable to oxidation in a pure oxygen environment, and provide improved performance and longer life are desired.

#### **Deionizing Water Treatment for High Pressure, High Temperature Water Electrolyzers**

Ultra high purity water is needed for NASA's high pressure, high temperature water electrolyzers. Technology is needed to remove ions within the water that is circulated over the catalyzed electrodes of the electrolyzer. Ions need to be reduced below TBD ppm prior to entering the water electrolyzer. The deionizer must function in flowing water at 2000 psi and 80°C.

#### **High System Pressure water Pump**

A water pump is needed to circulate water through a high-pressure water electrolyzer. The pump must meet the following criteria:

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- Operating System pressure of >2000 psia.
  - Minimum developed differential pressure of 30 psid.
  - Operating temperature 20-90°C.
  - Minimum liquid flow rate of 30 LPM.
  - Chemically tolerant to water saturated with dissolved oxygen at 2000 psia, 90°C.
  - Tolerant to two-phase mixtures of gaseous oxygen and liquid water without losing pumping effectiveness.
  - Mass ? 2 kg.
  - Volume ? 0.75 liters.
  - Power Consumption ? 120 watts.

### **Instrumentation, Control, Health Monitoring, and Data Handling**

Highly reliable voltage monitors for batteries, fuel cells, electrolyzers, and regenerative fuel cells are needed having low mass and low parasitic power consumption. Up to 48 differential voltages (0-5 VDC) with a minimum of 120 VDC common mode rejection must be monitored for system health management over an operating temperature range of -20 to +40°C, and the system must be capable of being upgraded to meet a Grade-1 EEE reliability

### **Solid Oxide Fuel Cells and Electrolyzers**

Advanced primary Solid Oxide Fuel Cells (SOFC) and Electrolyzers offer notable advantages in certain space applications when integrated with, respectively, CH<sub>4</sub>/O<sub>2</sub> propulsion systems and systems for producing oxygen from planetary resources. In contrast to most terrestrial/commercial applications, solid oxide devices for spacecraft will operate on pure oxygen and clean fuel streams (e.g., pure methane.) New materials are required to enable their use in these applications. These devices typically operate at high temperatures (800-1000°C) and are expected to undergo on/off cycling in aerospace applications. Technology advances are sought that reduce the time required to get to operating temperature, enable hundreds of rapid start-up/shut-down cycles, and enable systems to accommodate large load swings without leakage or deposition of elemental carbon. Spacecraft solid oxide devices that operate with minimal active cooling are needed. Low recurring costs are not a priority for spacecraft fuel cell materials. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of Solid Oxide Fuel Cells and Electrolyzers are desired. Proposals are sought which address the following areas:

#### **Advanced Primary SOFC Systems**

Their high temperature heat rejection and high efficiency power generation from methane and oxygen make primary SOFC's attractive for application to spacecraft with CH<sub>4</sub>/O<sub>2</sub> propulsion systems. Research directed towards improving the durability, efficiency, and reliability of SOFC systems fed by propellant-grade methane and oxygen is desired. Primary SOFC components and systems of interest:



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- Have power outputs in the 1 to 3 kW range.
  - Offer thermodynamic efficiencies of at least 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.
  - Operate as specified after at least 300 start-up cycles (from cold to operating temperature within 5 minutes) and 300 shut-down cycles (from operating temperature to cold within 5 minutes).
  - Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen.
  - Are cooled by way of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

### **Advanced Solid Oxide Electrolyzers**

Their high temperature heat rejection and operation, along with high efficiency, make solid oxide electrolyzers attractive as the final step of producing oxygen from Lunar or Martian regolith by way of hydrogen or carbothermal reduction. They are also attractive components for Sabatier reactors producing methane from the Martian atmosphere. Research directed towards improving the durability, efficiency, and reliability of solid oxide electrolyzers is desired. Solid oxide electrolysis systems of interest:

- Require power inputs in the 1 to 3 kW range.
- Operate as specified after 10,000 hours of operation fed by water with mild contamination.
- Operate as specified after 100 start-up cycles (from cold to operating temperature within 5 minutes) and 100 shut-down cycles (from operating temperature to cold within 5 minutes).
- Offer thermodynamic efficiencies of at least 70% (DC-input to Lower Heating Value H<sub>2</sub> output) when operating at the current feed corresponding to rated power.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

### **X8.02 Space-Rated Batteries**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC

Advanced battery systems are sought for future NASA Exploration missions to address requirements for safe, human-rated, high specific energy, high energy density, and high efficiency power systems. Possible applications include extravehicular activities, landers, and rovers. Areas of emphasis include advanced cell chemistries with aggressive weight and volume performance improvements and safety advancements over state-of-the-art lithium-based systems. Novel rechargeable battery chemistries with advanced non-toxic anode and cathode materials and

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nonflammable electrolytes are of particular interest. Priority will be given to efforts addressing novel cathode materials that can be paired with advanced silicon anodes.

The focus of this solicitation is on advanced concepts and cell components that provide weight and volume improvements and safety advancements that contribute to the following cell level metric goals:

- Specific energy >350 Wh/kg at C/2 (Fully charged or discharged in 2 hours).
- Energy density > 650 Wh/l at C/2.
- Tolerance to abuse such as overcharge, external short-circuit, and over temperature.
- Calendar life >10 years.
- Cycle life >250 cycles at 100% depth of discharge.

Systems that combine all of the above characteristics and demonstrate a high degree of safety and radiation tolerance are desired. Cell safety devices such as shutdown separators, current limiting devices that inhibit thermal runaway, venting, and eliminate flame or fire; autonomous safety features that include safe, non-flammable, non-hazardous operation especially for human-rated applications are of particular interest.

Proposals should include analysis that demonstrates the potential of the proposed technology to meet the projected performance parameters. Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II breadboard demonstration, and when possible, deliver a prototype/ demonstration unit for functional and environmental testing at the completion of the Phase II contract.

### **X8.03 Space Nuclear Power Systems**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC, MSFC

NASA is developing fission power system technology for future space transportation and surface power applications using a stepwise approach. Early systems are envisioned in the 10 to 100 kWe range that utilize a 900 K liquid metal cooled reactor, dynamic power conversion, and water-based heat rejection. The anticipated design life is 8 to 15 years with no maintenance. Candidate mission applications include initial power sources for human outposts on the moon or Mars, and nuclear electric propulsion systems (NEP) for Mars cargo transport. A non-nuclear system ground test in thermal-vacuum is planned by NASA to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance.

The primary goals for the early systems are low cost, high reliability, and long life. Proposals are solicited that

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could help supplement or augment the planned NASA system test. Specific areas for development include:

- 900 K NaK heat transport loops, including pumps and accumulators.
- 10 kWe-class Stirling and Brayton power conversion devices.
- 450 K water heat rejection loops, including pumps and accumulators.
- Composite radiator panels with embedded water heat pipes.
- Radiator deployment mechanisms and structures.
- Radiation tolerant materials and components.
- 120 V - 1k V power management and distribution (PMAD) for high power DC and AC systems, 1 kW to 100 kW respectively.

The NASA system test is expected to provide the foundation for later systems in the multi-hundred kilowatt or megawatt range that utilize higher operating temperatures, alternative materials, and advanced components to improve system performance. For the later systems, specific power will be a key performance metric with goals of 30 kg/kWe at 100 kWe and 10 kg/kWe at 1 MWe. Possible mission applications include large NEP cargo vehicles, NEP piloted vehicles, and surface-based resource production plants. In addition to low cost, high reliability, and long life, the later systems should address the low system specific mass goal. Proposals are solicited that identify novel system concepts and methods to reduce mass and increase power output. Specific areas for development include:

- High temperature reactor fuels and structural materials.
- Reactor heat transport technologies for 1100 K and above.
- 100 kWe-class Brayton and Rankine power conversion devices.
- Waste heat rejection technologies for 500 K and above.

#### **X8.04 Advanced Photovoltaic Systems**

**Lead Center:** GRC

**Participating Center(s):** JPL, JSC

Advanced photovoltaic (PV) power generation and enabling power system technologies are sought for improvements in capability and reliability of PV power generation for space exploration missions. Power levels for PV applications may reach 100s of kWe. System and component technologies are sought that can deliver efficiency, cost, reliability, mass and volume improvements under various operating conditions.

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PV technologies must enable or enhance the ability to provide low-cost, low mass and higher efficiency for power systems with particular emphasis on high power arrays to support solar electric propulsion missions. Examples of PV technology areas:

- Very large solar array concepts (>300kW) operating at high voltage (>200V).
- High voltage electronics for use in solar electric propulsion vehicles operating at bus voltages >200 VDC.
- Advanced concepts for array packaging, deployment and retraction.
- Advanced PV blanket and component technology/designs.
- Array concepts and module/component technologies that emphasize cost reduction (in materials, fabrication and testing).
- Automated/modular fabrication methods.
- Component and material availability/ high volume production capability.
- Ground testability/ space qualification for large array structures.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies that address exploration mission needs but also benefit clean/ renewable energy for terrestrial applications.

## Entry, Descent, and Landing (EDL) Technology Topic X9

The Entry, Descent, and Landing (EDL) Technology includes developments in Thermal Protection Systems (TPS) and Supersonic Retropropulsion (SRP). The Thermal Protection System (TPS) protects a spacecraft from the severe heating encountered during hypersonic flight through a planetary atmosphere. Supersonic Retropropulsion has been identified in past studies to be enabling for putting human-scale payloads on the surface of Mars. Thermal Protection Systems: In general, there are two classes of TPS: reusable and ablative. Typically, reusable TPS applications are limited to relatively mild entry environments like that of Space Shuttle. No change in the mass or properties of the TPS material results from entry; a significant amount of energy is re-radiated from the heated surface and the remainder is conducted into the TPS material. Ablative TPS materials, in contrast, accommodate

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high heating rates and heat loads through phase change and mass loss. All NASA planetary entry probes to date have used ablative TPS. Most ablative TPS materials are reinforced composites employing organic resins as binders. In comparison to reusable TPS materials, the interaction of ablative TPS materials with the surrounding gas environment is much more complex as there are many more mechanisms to accommodate the entry heating. Better performing ablative TPS is needed to satisfy requirements of the most severe missions, e.g., Mars Landing from 8 km/s entry and Mars Sample Return with 12-15 km/s Earth entry. Beyond the improvement needed in ablative TPS materials, more demanding future missions such as large payload missions to Mars will require novel entry system designs that consider different vehicle shapes, deployable or inflatable configurations and integrated approaches of TPS materials with the entry system sub-structure. Supersonic Retropropulsion: When decelerating a vehicle to land on a body with an atmosphere, it is generally more mass-effective to take advantage of the natural environment and use atmospheric drag to its full potential, rather than use a propulsion system. This approach works well at Earth where the atmosphere is dense, but the trade is less conclusive at Mars. Recent studies for landing human-scale payloads on Mars (40-60 mt) have shown that using Supersonic Retropropulsion is probably enabling for this challenge. The scale of an aerodynamic decelerator employed in this flight regime would be very large, and presents issues with payload extraction and deployment in the short time available. Since a terminal propulsion system is already needed for these large landers, starting the engines earlier in the descent profile is an attractive solution. Aerodynamic challenges with this approach center around the interaction of the engine plumes with the oncoming supersonic flowfield, and what instabilities this causes for the system. Controlled wind tunnel testing with high-fidelity instrumentation and subsequent modeling of these complex flowfields is key to predicting system behavior. The SRP system will also need to be flight-tested in a relevant environment as part of the technology maturation. Cost-effective, feasible concepts and vehicle configurations for Earth flight tests are needed, to prove feasibility in the near term.

Sub Topics:

## **X9.01 Ablative Thermal Protection Systems**

**Lead Center:** ARC

**Participating Center(s):** GRC, JPL, JSC, LaRC

The technologies described below support the goal of developing higher performance ablative TPS materials for future Exploration missions. Developments are sought for ablative TPS materials and heat shield systems that exhibit maximum robustness, reliability and survivability while maintaining minimum mass requirements, and are capable of enduring severe combined convective and radiative heating, including: development of acreage (main body, non-leading edge) materials, adhesives, joints, penetrations, and seals. Three classes of materials will be required:

- One class of materials, for Mars aerocapture and entry for a rigid mid L/D (lift to drag ratio) shaped vehicle, will need to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm<sup>2</sup> (primarily convective) and integrated heat loads of up to 55 kJ/cm<sup>2</sup>, and the second at heat fluxes of 100-200 W/cm<sup>2</sup> and integrated heat loads of up to 25 kJ/cm<sup>2</sup>. These materials or material systems must improve on the current state-of-the-art recession rates of 0.25 mm/s at heating rates of 200 W/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm<sup>2</sup> required to maintain a bondline temperature below 250°C
- The second class of materials, for Mars aerocapture and entry for a hypersonic deployable aerodynamic decelerator, will need to survive a dual heating exposure, with the first at heat fluxes of 100-200 W/cm<sup>2</sup> (primarily convective) and integrated heat loads of 10 kJ/cm<sup>2</sup> and the second at heat fluxes of 30-50 W/cm<sup>2</sup> and heat loads of 5 kJ/cm<sup>2</sup>. These materials may be either flexible or deployable.
- The third class of materials, for Mars return, will need to survive heat fluxes of 1500-2500 W/cm<sup>2</sup>, with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm<sup>2</sup>. These materials, or material systems must improve on the current state-of-the-art recession rates of 1.00 mm/s at heating rates of 200 W/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm<sup>2</sup>, required to maintain a bondline temperature below 250°C.

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In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data will lead to higher fidelity design tools, risk reduction, decreased heat shield mass and increases in direct payload. The heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values.

Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void detection requirements are on the order of 6-mm, and bondline defect detection requirements are on the order of 25.4-mm by 25.4-mm by the thickness of the adhesive.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring. There is a specific need for improved models for low and mid density as well as multi-layered charring ablators (with different chemical composition in each layer). Consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver, should be included in the modeling efforts.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

## **X9.02 Advanced Integrated Hypersonic Entry Systems**

**Lead Center:** ARC

**Participating Center(s):** GRC, JPL, JSC, LaRC

The technologies below support the goal of developing advanced integrated hypersonic entry systems that meet the longer-term goals of realizing larger payload masses for future Exploration missions.

Advanced integrated thermal protection systems are sought that address:

- Thermal performance efficiency (i.e., ablation vs. conduction).
- In-depth thermal insulation performance (i.e., material thermal conductivity and heat capacity vs. areal density).
- Systems thermal-structural performance.

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- System integration and integrity.

Such integrated systems would not necessarily separate the ablative TPS material system from the underlying sub-structure, as is the case for most current NASA heat shield solutions. Instead, such integrated solutions may show benefits of technologies such as hot structures and/or multi-layer systems to improve the overall robustness of the integrated heat shield while reducing its overall mass. The primary performance metrics for concepts in this class are increased reliability, reduced areal mass, and/or reduced life cycle costs over the current state of the art.

Advanced multi-purpose TPS solutions are sought that not only serve to protect the entry vehicle during primary planetary entry, but also show significant added benefits to protect from other natural or induced environments including: MMOD, solar radiation, cosmic radiation, passive thermal insulation, dual pulse heating (e.g., aero capture followed by entry). Such multi-purpose materials or systems must show significant additional secondary benefits relative to current TPS materials and systems while maintaining the primary thermal protection efficiencies of current materials/systems. The primary performance metrics for concepts in this class are reduced areal mass for the combined functions over the current state of the art.

Integrated entry vehicle conceptual development is sought that allow for very high mass ( $> 20$  mT) payloads for Earth and Mars entry applications. Such concepts will require an integrated solution approach that considers: TPS, structures, aerodynamic performance (e.g.,  $L/D$ ), controllability, deployment, packaging efficiency, system robustness/reliability, and practical constraints (e.g., launch shroud limits, ballistic coefficients, EDL sequence requirements, mass efficiency). Such novel system designs may include slender or winged bodies, deployable or inflatable entry systems as well as dual use strategies (e.g., combined launch shroud and entry vehicle). New concepts are enabling for this class of vehicle. Key performance metrics for the overall design are system mass, reliability, complexity, and life cycle cost.

Advances in Multidisciplinary Design Optimization (MDO) are sought specifically in application to address combined aerothermal environments, material response, vehicle thermal-structural performance, vehicle shape, vehicle size, aerodynamic stability, mass, vehicle entry trajectory/GN&C (Guidance, Navigation and Control), and cross-range, characterizing the entry vehicle design problem.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

## Cryogenic Propellant Storage and Transfer Topic X10

The Exploration Systems architecture presents cryogenic storage, distribution, and fluid handling challenges that require new technologies to be developed. Reliable knowledge of low-gravity cryogenic fluid management behavior

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is lacking and yet is critical for future manned and robotic exploration in the areas of storage, distribution, and low-gravity propellant management. Additionally, Earth-based and planetary surface missions will require success in storing and transferring liquid and gas commodities in applications. Some of the technology challenges are for long-term space use cryogenic propellant storage and distribution; cryogenic fluid processing and fluid conditioning; liquid hydrogen and liquid oxygen liquefaction processes. Furthermore, specific technologies are required in valves, regulators, instrumentation, modeling, mass gauging, cryocoolers, and passive and active thermal control techniques. The technical focus for component technologies are for accuracy, reduced mass, minimal heat leak, minimal leakage, and minimal power consumption. The anticipated technologies proposed are expected to increase safety, reliability, economic efficiency over current state-of-the-art cryogenic system performance, and are capable of being made flight qualified and/or certified for the flight systems and dates to meet Exploration Systems mission requirements.

Sub Topics:

### **X10.01 Cryogenic Fluid Management Technologies**

**Lead Center:** GRC

**Participating Center(s):** ARC, GSFC, JSC, KSC

This topic solicits technologies related to cryogenic propellant storage, transfer, and instrumentation to support NASA's exploration goals. Proposed technologies should feature enhanced safety, reliability, long-term space use, economic efficiency over current state-of-the-art, or enabling technologies to allow NASA to meet future space exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Specifically:

- Innovative concepts for cryogenic fluid instrumentation are solicited to enable accurate measurement of propellant mass in low-gravity storage tanks, sensors to detect in-space and on-pad leaks from the storage system, minimally invasive cryogenic liquid mass flow measurement sensors, including cryogenic two-phase flow.
- Passive thermal control for Zero Boil-Off (ZBO) storage of cryogenics for both long term (>200 days) and short term (~14 days) in all mission environments. Insulation systems that can also serve as Micrometeoroid/orbital debris (MMOD) protection and are self-healing are also desired.
- Active thermal control for long term ZBO storage for space applications. Technologies include 20K cryocoolers and integration techniques, heat exchangers, distributed cooling, and circulators.
- Zero gravity cryogenic control devices including thermodynamic vent systems, spray bars, mixers, and liquid acquisition devices.
- Advanced spacecraft valve actuators using piezoelectric ceramics. Actuators that can reduce the size and power while minimizing heat leak and increasing reliability.
- Large scale propellant conditioning and densification technologies for zero loss propellant storage and transfer. Specific component technologies include compact, efficient and economical cryogenic compressors, cryocoolers and integration techniques, Joule-Thompson orifices, vapor shielded transfer lines, and heat exchangers.
- Liquefaction of oxygen for in space resource utilization applications. This includes passive cooling with low temperature radiators, cryocooler liquefaction, or open cycle systems that work with HP electrolysis.
- Processes or components/instrumentation that can reduce or eliminate helium usage. This includes real time purge gas concentration visibility, helium capture and purification technology, and alternatives to helium use such as hydrogen gas purges or advanced insulation systems.



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## Radiation Protection Topic X11

The SBIR topic area of Radiation Protection focuses on the development and testing of mitigation concepts to protect astronaut crews and exploration vehicles from the harmful effects of space radiation, both in Low Earth Orbit (LEO) and while conducting long-duration missions beyond LEO. Advances are needed in mitigation schema for the next generation of exploration vehicles inclusive of radiation shielding materials and structures technologies to protect humans from the hazards of space radiation during NASA missions. As NASA continues to form plans for long duration exploration, it has also become increasingly clear that the ability to mitigate the risks posed to both crews and vehicle systems by the space weather environment are also of central importance. This Radiation Protection Topic will have two sub-topics consisting of:

- Radiation Shielding.
- Alert and Warning Systems.

This first area of interest for the 2011 solicitation is radiation shielding materials systems for long-duration Galactic Cosmic Ray (GCR) and Solar Particle Event (SPE) protection capable of providing structural integrity for architectural element design, while also providing sufficient radiation protection. These material systems should likely possess other multi-functional properties such as thermal and/or MMOD protection, etc., therefore negating the need for the addition of parasitic shield mass. Neutron protection and high-energy electron protection are also of interest. Research should be conducted to demonstrate technical feasibility during Phase I and to show a path forward to Phase II technology demonstration. Physical, mechanical, structural, and/or other relevant characterization data to validate and qualify multifunctional radiation shielding materials and structures should be demonstrated. Advances are needed in:

- Innovative tailored materials for lightweight radiation shielding of humans and electronics for NASA missions.
- Innovative, multifunctional, integrated, or multipurpose structures (primary or secondary structure) for lightweight radiation shielding of humans and electronics for NASA missions.

Applications are expected to include space exploration vehicles including launch vehicles, crewed vehicles, and surface and habitat systems. Another area of interest in which SBIR-developed technologies can contribute to NASA's overall mission requirements are advances in the understanding and predictability of space weather science. Current operational space weather support utilizes both inter- and extra-agency assets to maintain situational awareness and mitigate radiation risks associated with agency missions. Operational space weather support consists in the most basic terms of maintaining situational awareness of both the state of the Sun as a physical system and the radiation environment and its dynamics within the Heliosphere, and altering in real-time, a mission in order to minimize their effects. Therefore, advances are needed in the development of scientific research products for real-time operational forecasting tools to mitigate mission risk. Research under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path forward to Phase II hardware

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demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Sub Topics:

### **X11.01 Radiation Shielding Materials Systems**

**Lead Center:** LaRC

**Participating Center(s):** MSFC

Advances in radiation shielding materials technologies and systems are needed to protect humans from the hazards of space radiation during NASA missions. The primary areas of interest for this 2011 solicitation are radiation shielding materials systems for long-duration galactic cosmic radiation (GCR) and solar energetic particles (SEP) protection. Neutron protection and high-energy electron protection are also of interest. Research should be conducted to demonstrate technical feasibility during Phase I and to show a path toward a Phase II technology demonstration.

Physical, mechanical, structural, and/or other relevant characterization data to validate and qualify multifunctional radiation shielding materials should be demonstrated. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements include the following:

- Innovative tailored materials for lightweight radiation shielding of humans.
- Innovative, multifunctional, integrated, or multipurpose structures (primary or secondary structures) for lightweight radiation shielding of humans.
- Innovative processes for developing radiation shielding materials.
- Smart, or sensing, radiation shielding materials.
- Radiation shielding materials demonstration experiments for MISSE (Materials International Space Station Experiment) or other ISS experiments.

### **X11.02 Integrated Advanced Alert/Warning Systems for Solar Proton Events**

**Lead Center:** JSC

Advances are needed in alerts/warnings and risk assessment models that give mission planners, flight control teams and crews sufficient advanced warning of impending Solar Proton Event impact. Research and development should be targeted which leverages modeling techniques used throughout terrestrial weather for extreme event assessment. There is particular interest in development of models capable of delivering the probability of no SPE occurrence in a 24-hour time period, i.e., an "All-Clear" forecast.

Forecast techniques should utilize the historical record of archived SPEs to characterize model forecast validity in terms accepted metrics, i.e., skill score, false alarm rates, etc. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements include the following:

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Innovative forecasting solutions that leverage model development in other areas such as ensemble forecasting of hurricane tracks, flooding, financial market behavior, and earthquake prediction.

Innovative methods that integrate historical trending, real-time data, and fundamental physics-based models into advance warning and detection systems.

## Exploration Crew Health Capabilities Topic X12

Human space flight is associated with losses in muscle strength, bone mineral density and aerobic capacity. Crewmembers returning from the International Space Station (ISS) can lose as much as 10-20% of their strength in weight bearing and postural muscles. Likewise, bone mineral density is decreased at a rate of ~1% per month. During future exploration missions such physiologic decrements represent the potential for a significant loss of human performance which could lead to mission failure and/or a threat to crewmember health and safety. NASA is conducting research to enhance and optimize exercise countermeasure hardware and protocols for these missions. In this solicitation, we are seeking portable technologies to collect foot ground reaction force data from current exercise hardware deployed on the International Space Station to be analyzed by research teams on the ground, as well as compact, low mass, low power, high life-cycle, force-generating components for application to future crew exercise concepts.

Sub Topics:

### **X12.01 Crew Exercise Systems**

**Lead Center: GRC**

**Participating Center(s): JSC**

NASA seeks compact, low mass, low power, hi life-cycle, force-generating components for application to future crew exercise equipment - capable of providing aerobic and resistive (>700 lbs) loads over a range of load increments of 5 lbs. for each load setting 100 lbs., and with adjustable stroke range up to 70 inches, while providing return: pull stroke load ratios of 0.9:1.0 or greater (e.g., 1.0:1.0 better, or 1.1:1.0 best) over the entire range of motion.

Phase I Deliverable: Fully developed concept complete with feasibility and top-level drawings/computational methodology as applicable. A breadboard or prototype system is highly desired.

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## **X12.02 Portable Load Sensing Systems**

**Lead Center:** GRC

**Participating Center(s):** JSC

NASA seeks a portable, force/load measurement system capable of being integrated into existing International Space Station (ISS) exercise systems. During long duration spaceflight, exercise countermeasures are prescribed to mitigate bone and muscle loss. However, advancement of these exercise prescriptions may require biomechanical analysis of exercise on orbit. Output parameters from the proposed device must operate in the bandwidth from 0-100Hz and be able to be synchronized with existing analog data systems. Vertical and shear forces are required and the portable system should be low-maintenance, durable, easy to set-up and calibrate, non-disruptive to exercise form (e.g., running, squat, dead lift, and calf raises), reliable, accurate (

Phase I Deliverable: Fully developed concept complete with feasibility and top-level drawings/computational methodology as applicable. A breadboard or prototype system is highly desired.

## **Exploration Medical Capability Topic X13**

Further human exploration of the solar system will present significant new challenges to crew health including hazards created by traversing the terrain of asteroids or planetary surfaces and the effects of variable gravity environments. The limited communications with ground-based personnel for diagnosis and consultation of medical events creates additional challenges. Providing health care capabilities for exploration missions will require the definition of new medical requirements and development of technologies to ensure the safety and success of Exploration missions, pre-, in-, and post-flight. This SBIR Topic addresses some key medical technology and gaps that NASA will need to solve in order to proceed with exploration missions.

Sub Topics:

### **X13.01 Smart Phone Driven Blood-Based Diagnostics**

**Lead Center:** JSC

**Participating Center(s):** ARC

As user applications pervade the field of telemedicine, smart phones provide a robust, reconfigurable platform capable of communications, computations and various functions (i.e., imaging, video, power source, signal processing) that will continue to expand at an accelerated pace. By leveraging this technology, NASA seeks to exploit the smart phone for blood-based diagnostics to develop an analytical device that can determine basic metabolic (Chem8), blood gas ( $\text{PaO}_2$ ,  $\text{PaCO}_2$ ,  $\text{SaO}_2$ ,  $\text{HCO}_3$ , pH), cardiac (troponin I, CK-MB, total cholesterol, HDL, LDL, VDL, triglycerides and lipoproteins) and liver/renal (total bilirubin, direct bilirubin, ALP, ALT, AST) panels. These panels are representative of the operational and research requirements for space exploration related point of care diagnostics.

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The diagnostic device must interface to a smart phone that will drive the device's electronics and/or optics; or use the built-in features of the phone to interrogate the diagnostic device. The described diagnostic component is to be no larger than the phone itself. The microfluidic device must also be reusable or extremely compact if disposable, and minimize reagent consumption. Other requirements to consider are analytical times in two minutes or less, strategies for operational capability up to 144 hours on battery power and a long shelf-life (> 36 months).

The Phase I effort will seek to demonstrate the feasibility of one diagnostic panel in the smart phone format. The Phase II effort will demonstrate at least two of the above stated panels in an analytical component that interfaces to a cell phone, and provides a path towards FDA approval or similar.

NASA Deliverable: Functional Diagnostic System

### **X13.02 Non-Wet Prep Electrodes**

**Lead Center:** JSC

**Participating Center(s):** ARC

Although physiological monitoring has been conducted since the earliest human flights, there has not been substantial improvement in the technology of the sensors used in space since those early years. The current systems on the International Space Station (ISS) are still using wet-prep electrodes - which are time consuming and inconvenient, requiring shaving, application of electrodes, signal checks, and management of lead wires. Skin irritation sometimes develops from the electrode's interactions with roughened skin. And the signals are still subject to noise, corruption, and loss.

NASA desires a non-wet prep sensor system that:

- Is easy to don/doff (requires no shaving or skin prep), has no disposables, and can be worn comfortably for 48 hours.
- Maintains signal integrity at clinical quality (meets or exceeds ANSI/AAMI EC11 Standard for Diagnostic Electrocardiographic Devices) during rigorous exercise.
- Solutions that partially involve software (as opposed to strictly hardware) are acceptable, but any developed software code must be easily integrated into the ECG software system(s) used by NASA and not just into the given company's proprietary and/or standalone product.

NASA Deliverable: Functioning sensor system

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## Behavioral Health and Performance Topic X14

The Behavioral Health and Performance topic is interested in developing strategies, tools, and technologies to mitigate Behavioral Health and Performance risks. The Behavioral Health and Performance topic is seeking tools and technologies to prevent performance degradation, human errors, or failures during critical operations resulting from: fatigue or work overload; deterioration of morale and motivation; interpersonal conflicts or lack of team cohesion, coordination, and communication; team and individual decision-making; performance readiness factors (fatigue, cognition, and emotional readiness); and behavioral health disorders. For 2011, the Behavioral Health and Performance topic is interested in the following technologies: Virtual reality and world technologies for team training approaches.

Sub Topics:

### **X14.01 Virtual Reality and World Technologies for Team Training Approaches**

**Lead Center: JSC**

This subtopic is to develop a virtual reality training environment to support pre-mission and just-in-time training for exploration crews and controllers. The training should encompass individual interactions with other team members as well as with the environment.

NASA wishes to identify how virtual reality and world technologies could be used to train crews and controllers on topics such as cross-cultural interactions, leadership, psychological support, and effective interactions with other team members or artificial intelligent agents while attempting to complete complicated, multi-agent (human or robotic) tasks.

The proposal should provide a framework describing:

- The virtual environment to be developed.
- Platform in which training will be experienced.
- How the training will allow the interaction with others (multi-player online or artificial intelligent agents), specific suggestions as to how to evaluate the training module's effectiveness and prediction of team performance and other important team outcomes and an assessment to determine the feasibility of the proposed training modules in the technical skill domains.

NASA Deliverables: Phase I deliverable should yield a proof of concept which includes both a literature review that

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encompasses an assessment of current knowledge of virtual reality technologies and its use in team training. In addition, the following deliverables will be required:

- A requirements document for such a training module.
- An evaluation plan for assessing the effectiveness of the training module on team outcomes.

The subsequent Phase II deliverable would provide a prototype of specific training modules that can demonstrate improved team performance (including task performance metrics) by utilizing these training technologies.

## Space Human Factors and Food Systems Topic X15

The emphasis on developing new, innovative technologies to enable future space exploration encompasses a need for new approaches in the areas of Space Human Factors and Food Systems. Operations in confined, isolated, and resource-constrained environments can lead to suboptimal human performance. Research and development activities in this topic address challenges that are fundamental to design, development, and operation of the next generation crewed space vehicles. These challenges include:

- Development of a software tool that automatically processes crew motion and interaction, either on orbit or on the ground, from video footage taken with a single conventional 2D camera to enable unobtrusive and non-invasive measurement of task performance and crew behavioral health.
- A need to develop a technology or system capable to prevent vitamin degradation of naturally-occurring and supplemented vitamins within a food substrate stored at ambient temperatures for five years.  
(<http://humanresearchroadmap.nasa.gov/evidence/> [1],  
<http://www.nasa.gov/centers/johnson/slsd/about/divisions/hefd/index.html> [2])

Sub Topics:

### **X15.01 A New Technique for Automated Analyses of Raw Operational Videos**

**Lead Center:** JSC

**Participating Center(s):** ARC

Develop a software tool that automatically processes raw motion video footage (from a single conventional 2D

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camera) of a crew (spacecraft or ground) during a space mission.

Such a tool is needed to address vehicle/habitat design issues, as well as crew-to-crew interaction issues, on the ground. For example, unprocessed space mission operational videos down linked from a spacecraft that involve humans as the subjects of interest need to be analyzed on the ground for their motion and behavioral health information.

#### Requirements:

- The raw video data shall be video footages from a single conventional 2D camera and with no special lighting or fiducial markers.
- The processed data shall contain the subjects' geometric information (position, movement, acceleration) relative to their operational environment and crewmates.
- A "tool chest" shall be available for visualization aids, velocity computations, etc. For visualization aids, the tool chest shall enable the user to specify areas or actions of interest. The software shall then locate, mark, count, etc. to indicate how many times the crew accessed a piece of hardware, traversed a path, reached above their heads, etc.

Desirable: 3D information extraction - ability to extract 3D information from the raw video to enable high-precision human motion analyses using the software's tool chest.

Phase I Deliverable: Algorithm

Phase II Deliverable: Functional software prototype

## **X15.02 Advanced Food Technologies**

**Lead Center:** JSC

**Participating Center(s):** JSC

The purpose of the NASA Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on long duration missions beyond low-Earth orbit. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 - 5 years will be required to support the crew during these exploration missions. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time.

Refrigeration and freezing require dispensable resource utilization, so NASA provisions consist solely of shelf



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stable foods. Stability is achieved by thermal or irradiative processing to kill the microorganisms in the food or drying to prevent viability of the microorganisms. These methods do impact the micronutrients within the food substrate. Environmental factors (such as moisture ingress and oxidation) are also capable of compromising the nutrient content over the shelf life of the food. Since the food system is the designated source of nutrition to the crew, a significant loss in nutrient availability could significantly jeopardize the health and performance of the crew. Optimal nutritional content of the food for up to five years will ensure that the food can support crew performance and help protect their bodies from deficiencies that cause disease.

Vitamin content in NASA foods, such as Vitamin C, Vitamin A, thiamin, and folic acid, is degraded during processing and as the product ages in storage. The goal is to develop a system that protects the vitamins from this degradation at ambient temperatures over a five year duration. Possible technologies that could be investigated to protect food ingredients from biological and chemical degradation of components over time include nanoscale technologies (e.g., encapsulation), biosensors, novel food ingredients, and controlled-release systems. Technologies or systems that could aid in increasing the bioavailability of the nutrients should also be considered.

Phase I Requirements: Phase I should concentrate on the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses.

NASA Deliverable: A system which will result in higher nutrient content in shelf stable foods.

## Space Radiation Topic X16

The goal of the NASA Space Radiation Research Program is to assure that we can safely live and work in the space radiation environment, anywhere, any time. Space radiation is different from forms of radiation encountered on Earth. Radiation in space consists of high-energy protons, heavy ions and secondary products created when the protons and heavy ions interact with matter such as a spacecraft, surface of a planet, moon, asteroid, or even the astronauts themselves. NASA requires instruments that can reliably measure these radiations. NASA has a need for compact active radiation detection systems that can meet stringent size, power, and performance requirements. These include real-time personal monitors and area monitors that can be used on the International Space Station (ISS) as well as on future missions beyond low-Earth orbit (LEO). Ending the Space Shuttle program will increase the need to replace the current passive monitoring technologies on the ISS with active ones to reduce up and down mass. Also, as missions extend beyond LEO there will be further premium on reduced size, mass, and power for radiation detection technologies. To achieve such reductions, there will be an increasing need for reliable miniaturized components such as sensors, photomultipliers, data processors, power supplies, and the like that can be used to enhance radiation detection technologies as they develop. Advanced technologies up to technology readiness level (TRL) 4 are requested in these and related areas.

Sub Topics:

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## **X16.01 Radiation Measurement Technologies**

**Lead Center:** ARC

NASA has a need for compact active radiation detection systems that can meet stringent size, power, and performance requirements. These include real-time personal monitors and area monitors that can be used on the ISS as well as on future missions beyond LEO. Ending the Space Shuttle program will increase the need to replace the current passive monitoring technologies on the ISS with active ones to reduce up and down mass. Also, as missions extend beyond LEO there will be further premium on reduced size, mass, and power for radiation detection technologies. To achieve such reductions, there will be an increasing need for reliable miniaturized components such as sensors, photomultipliers, data processors, power supplies, and the like that can be used to enhance radiation detection technologies as they develop. Advanced technologies up to technology readiness level (TRL) 4 are requested in these and related areas useful to NASA. Also, such advances would likely have potential customers outside NASA and in the commercial sector.

Metric and desired performance range:

### **Personal Monitors**

Sensitive to charged particles with LET of 0.2 to 500 keV/μm and detect charged particles (including protons) with energies 30 MeV/n to 1000 MeV/n. Design goals for mass should be 0.25 kg and for volume, 250 cm<sup>3</sup>. The monitor should be able to measure dose rate and dose-equivalent rate at both ambient conditions in space (0.01 mGy/hr) and during a large solar particle event (100 mGy/hr). Total power requirement should be in the 1 W range. Monitors shall perform data reduction internally and display dosimetry data in real time.

### **Area Monitors**

Same as Personal Monitors but extend LET to 1000 keV/μm and must also detect neutrons between 0.5 MeV and 150 MeV. Design goals for mass should be 1 kg and for volume should be 1000 cm<sup>3</sup>. Total power requirement should be less than 2 W. Monitors shall perform data reduction internally and display dosimetry data in real time.

### **Components**

These may include but are not limited to compact sensors with excellent response to space radiation (e.g., novel scintillation crystals, organic semiconductors, photodiodes), compact low-noise solid state photomultipliers that require less than 0.5 W of power, data processors not to exceed 0.2 W that can perform multi-channel analysis, low noise power supplies that require less than 0.3 W of power.

Phase I Deliverables: Proof of concept of the technologies requested.

Phase II Deliverables: Prototypes or components of the monitoring technologies meeting the requirements indicated.

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## Inflight Biological Sample Preservation and Analysis Topic X17

The Human Research Program (HRP) is an applied research and technology program aimed at providing human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. HRP's specific objectives include development of technologies that serve to reduce human systems resource requirements, such as mass, volume, and power to maximize utilization of spaceflight platforms to perform the essential research and technology development tasks that can only be accomplished during a space mission. Addressing multiple HRP human health and performance risks and knowledge gaps across various disciplines requires collection, preservation and analysis of biological samples from human subjects during a space mission, a common practice in clinical diagnostic medicine. However, the spaceflight environment affords unique challenges for the processing, storage and transport of biological specimens, due to highly constrained resources, such as limited conditioned stowage (mass and volume requiring storage in refrigerators or freezers) available. This topic aims to mitigate those space mission constraints by means of innovative approaches for the collection, long duration ambient temperature preservation, and low-resource small-footprint in situ analysis of human biospecimens, such as blood and urine, for a wide array of biomedically significant analytes.

Sub Topics:

### **X17.01 Alternative Methods for Ambient Preservation of Human Biological Samples During Extended Spaceflight and Planetary Operations**

Lead Center: JSC

Participating Center(s): ARC

Addressing multiple Human Research Program (HRP) human health and performance risks and knowledge gaps across various disciplines requires collection, preservation and analysis of biological samples from human subjects during a space mission, a common practice in clinical diagnostic medicine. However, the spaceflight environment affords unique challenges for the processing, storage and transport of biological specimens, due to highly constrained resources, such as very limited conditioned stowage (mass and volume requiring storage in refrigerators or freezers) to keep and return the biospecimens. This subtopic aims to mitigate those space mission constraints by means of innovative approaches for the long duration ambient temperature preservation of human biological samples, particularly blood and urine, while maintaining the integrity of a wide array of biomedically significant molecular markers for subsequent post-mission processing and analysis.

This subtopic seeks proposals for novel approaches to preserve analytes of clinical and research interest in human blood and urine samples for a minimum of one year at ambient temperature. Target blood analytes to be preserved include those in the Comprehensive Metabolic Panel: glucose, calcium, albumin, total protein, electrolytes (sodium, potassium, bicarbonate, chloride), kidney tests (blood urea nitrogen, creatinine), and liver tests (bilirubin, alkaline phosphatase, alanine amino transferase, aspartate amino transferase). Additional blood markers to be preserved include N-telopeptide, sulfate, highly specific C-reactive protein, tumor necrosis factor, interleukin-1, interleukin-6, 8-hydroxy-2-deoxy-guanosine, vitamin D, homocysteine, and selenium. For urine samples, the following analytes should be preserved: creatinine, cortisol, N- and C-telopeptides, hydroxyproline, 4-pyridoxic acid, 3-methylhistidine, G-carboxyglutamic acid, 8-hydroxy-2-deoxy-guanosine, uric acid, phosphorus, citrate, sulfate, oxalate, calcium, sodium, potassium, magnesium, and chloride. The proposed technology should be low-resource, low-footprint, and should involve a low volume of supplies/consumables, which do not require refrigeration or freezing for storage.

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NASA Deliverable: Prototype functional system for long duration room temperature preservation of human blood and/or urine biospecimens, demonstrating integrity for a subset of the target analytes (in Phase I).

#### In-Situ Resource Characterization, Extraction, Transfer, and Processing Topic X1.01

The ability to characterize, collect, transfer, and process resources at the site of exploration on the Moon, Mars, and Near Earth Objects (NEOs)/Phobos can completely change robotic and human mission architectures. The subtopic seeks proposals for the design and subsequent build of hardware and technologies that perform critical functions and operations for characterization, collection, transfer, and processing operations that can be inserted for integration into on-going and future system-level development and demonstration efforts. The technologies and hardware must utilize local materials with the minimum Earth-supplied feedstock possible. There are three main areas of interest:

#### Extraterrestrial Material-Based ISRU

- Methods for collection and transfer of NEO/Phobos material under micro-gravity conditions under vacuum/space environmental conditions. Proposals must state and explain material properties and water content considered in the design.
- Methods for the transfer of Mars surface material containing water at 1 to 5 kg/hr under Mars surface environmental conditions. Proposals must state and explain material properties and water content considered in the design, and locations on Mars where the method proposed is applicable
- Use of ionic liquids for processing and extracting oxygen and metals from extraterrestrial material at temperatures below 200 C at 0.2 kg/hr. Proposals must include methods for product separation and ionic liquid reagent regeneration for subsequent processing.
- Development of reactors with dust tolerant gas-tight seals and valving to extract and collect of water and other potential volatiles from extraterrestrial materials at 0.5 to 5 kg/hr of material processing rate. Proposals must state and explain material properties, water content, mixing technique, and gravity conditions considered in the design. Proposals may combine material transfer with water/volatile processing to minimize mass and power. Proposals for processing reactor systems should focus on highly effective approaches to energy utilization, including internal heat and mass transport enhancements and/or other physical or operational characteristics. Proposals that cover more than one material for consideration are of particular interest.
- Development of a compact, lightweight gas chromatograph - mass spectrometer (GC-MS) instrument that can quantify volatile gases released by sample heating below atomic number 70 (of particular interest H<sub>2</sub>, He (and isotopes), CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>O, N<sub>2</sub>, O<sub>2</sub>, Ar, NH<sub>3</sub>, HCN, H<sub>2</sub>S, SO<sub>2</sub>). The instrument should be designed to be able to withstand exposure to the release of HF, HCl, or Hg that may result from heating regolith samples to high temperatures. The instrument should be capable of detecting 1000 ppm to 100% concentration of the volatiles in the gas phase. The instrument should have a clear path to flight with a flight

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instrument design with a mass of less than 5 kg not including any vacuum components required to operate in the laboratory environment.

### **Extraterrestrial Atmosphere Based ISRU**

- Devices that collect and separate Mars atmospheric argon and nitrogen using a standalone device or as part of carbon dioxide collection concepts at carbon dioxide collection rates (0.5 to 2 kg CO<sub>2</sub>/hr rate and supply pressure at >15 psi for subsequent processing).
- Micro-channel reactor and heat exchanger concepts for efficient processing of carbon monoxide and carbon dioxide into water and/or methane with hydrogen at 0.5 to 2 kg/hr rate.

### **Discarded Material-Based ISRU**

- Trash processing reactor concepts for production of carbon monoxide, carbon dioxide, water, and methane from plastic trash and dried crew solid waste. Proposals must define use of solar or electrical energy during processing, and any reagents/consumables. Recycling schemes for reactants/reagents used in the processing should be included. Highly efficient, compact water vapor removal/separation devices from product gas streams is also of interest.

Proposals must consider the physical/abrasive, mineral, and volatile/water properties and characteristics of the material/resource of interest, and the gravity environment in which collection, transfer, and processing will occur. Concepts that can operate in micro & low-gravity (1/6-g & 3/8-g), as well as multiple resources are of greater interest. Designs that are compatible for subsequent analog, micro/low-g flight experiments, and ground vacuum experiments are also of greater interest. Proposals that utilize rotating gears and actuators must be designed for abrasive/dusty environmental conditions. Proposals will be evaluated against state-of-the-art capabilities with respect to mass, power, and process efficiency. Figures of merit include consumable production rate (kg/hr), production energy efficiency (kg produced/ hr per KWe), and extraction/reactant recovery efficiency.

#### **Sub Topics:**

##### **Low Cost Heavy Lift Propulsion Topic X2.01**

Heavy lift launch vehicles envisioned for exploration beyond LEO will require large first stage propulsion systems. Total thrust at lift-off in will probably exceed 6 million pounds. There are available, in-production, practical propulsion options for such a vehicle. However, the cost for outfitting the booster with the required propulsion systems is in the hundreds of millions of dollars (2011 \$). This cost severely limits what missions NASA can perform. Low cost design concepts and manufacturing techniques are needed to make future exploration affordable.

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Objectives include:

Development of propulsion concepts whose cost is less than 50% of currently available heavy-lift propulsion options but with similar performance (i.e., reduced parts count, increased robustness to allow less expensive manufacturing techniques, less complex parts to maximize vendor competition, maximization of common parts, etc.) - both solid and liquid options are desired.

Development and demonstration of low-cost manufacturing techniques (i.e., use of rapid prototype techniques for metallic parts, application of nano-technology for manufacturing of near net shape manufacturing, etc.).

Sub Topics:

High Thrust In-Space Propulsion Topic X2.02

This solicitation intends to examine a range of key technology options associated with cryogenic, non-toxic storable, and solid core nuclear thermal propulsion (NTP) systems for use in future exploration missions. Non-toxic engine technology, including new mono and bi-propellants, is desired for use in lieu of the currently operational NTO/MMH engine technology. Handling and safety concerns with toxic chemical propellants can lead to more costly propulsion systems. For future short round trip missions to Mars, NTP systems using nuclear fission reactors may be enabling by helping to reduce launch mass to reasonable values and by also increasing the payload delivered for Mars exploration missions. Non-toxic and cryogenic engine technologies could range from pump fed or pressure fed reaction control engines of 25-1000 lbf up to 60,000 lbf primary propulsion engines. Pump fed NTP engines in the 15,000-25,000 lbf class, used individually or in clusters, would be used for primary propulsion.

Specific technologies of interest to meet proposed engine requirements include:

- Non-toxic bipropellant or monopropellants that meet performance targets (as indicated by high specific impulse and high specific impulse density) while improving safety and reducing handling operations as compared to current state-of-the-art storable propellants.
- High temperature, low burn-up carbide- and ceramic-metallic (cermet)-based nuclear fuels with improved coatings and /or claddings to maximize hydrogen propellant heating and to reduce fission product gas release into the engine's hydrogen exhaust stream.
- Low-mass propellant injectors that provide stable, uniform combustion over a wide range of propellant inlet temperature and pressure conditions.
- High temperature materials, coatings and/or ablatives or injectors, combustion chambers, nozzles, and nozzle extensions.
- High temperature and cryogenic radiation tolerant instrumentation and avionics for engine health monitoring. Non-invasive designs for measuring neutron flux (outside of reactor), chamber temperature, operating pressure, and liquid hydrogen propellant flow rates over wide range of temperatures are desired. Sensors need to operate for months/years instead of hours.

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- Combustion chamber thermal control technologies such as regenerative, transpiration, swirl or other cooling methods, which offer improved performance and adequate chamber life.
  - Long life, lightweight, reliable turbopump designs and technologies include seals, bearing and fluid system components. Hydrogen technologies are of particular interest.
  - Highly-reliable, long-life, fast-acting propellant valves that tolerate long duration space mission environments with reduced volume, mass, and power requirements is also desirable.
  - Radiation tolerant materials compatible with above engine subsystem applications and operating environments.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.04.

#### Sub Topics:

##### Electric Propulsion Systems Topic X2.03

The goal of this subtopic is to develop innovative technologies for high-power (100 kW to MW-class) electric propulsion systems. High-power (high-thrust) electric propulsion may enable dramatic mass and cost savings for lunar and Mars cargo missions, including Earth escape and near-Earth space maneuvers. At very high power levels, electric propulsion may enable piloted exploration missions as well. Improved performance of propulsion systems that are integrated with associated power and thermal management systems and that exhibit minimal adverse spacecraft-thruster interaction effects are of interest. Innovations are sought that increase system efficiency, increase system and/or component life, increase system and/or component durability, reduce system and/or component mass, reduce system complexity, reduce development issues, or provide other definable benefits. Desired specific impulses range from a value of 2000 s for Earth-orbit transfers to over 6000 s for planetary missions. System efficiencies in excess of 50% and system lifetimes of at least 5 years (total impulse > 1 x 10<sup>7</sup> N-sec) are desired. Specific technologies of interest in addressing these challenges include:

- Long-life, high-current cathodes (100,000 hours).
- Electric propulsion designs employing alternate fuels (ISRU, more storable).
- Electrode thermal management technologies.
- Innovative plasma neutralization concepts.
- Metal propellant management systems and components, and cathodes.
- Low-mass, high-efficiency power electronics for RF and DC discharges.
- Lightweight, low-cost, high-efficiency power processing units (PPUs).
- PPUs that accept variable input voltages of greater than 200V and vary by a factor of 2-to-1.
- Direct drive power processing units.
- Low-voltage, high-temperature wire for electromagnets.

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- High-temperature permanent magnets and/or electromagnets.
  - Application of advanced materials for electrodes and wiring.
  - Highly accurate propellant control devices/schemes.
  - Miniature propellant flow meters.
  - Lightweight, long-life storage systems for krypton and/or hydrogen.
  - Fast-acting, very long-life valves and switches for pulsed inductive thrusters.
  - Superconducting magnets.
  - Lightweight thrust vector control for high-power thrusters.
  - Fast-starting cathodes.
  - Propellantless cathodes.
  - High temperature electronics for power processing units.

Note to Proposer: Subtopic S3.04 under the Science Mission Directorate also addresses in-space propulsion. Proposals more aligned with science mission requirements should be proposed in S3.04.

#### Sub Topics:

Enabling Technologies for Biological Life Support Topic X3.01

#### **Biochemical Systems for CO<sub>2</sub> Removal and Processing to Useful Products**

NASA is interested in biochemical or biological systems and supporting hardware suitable for purifying the atmosphere in confined spaces such as crewed spacecraft or space habitat cabins. Of special interest is the removal and fixation of CO<sub>2</sub> from a cabin atmosphere via biochemical pathways or autotrophic organisms (plants, algae, cyanobacteria, etc) to produce oxygen and other useful products, including food. Processes considering photosynthesis must address how quantum and/or radiation use efficiency will be improved. Systems should consider minimizing power, mass, consumables and biologically produced waste, while maximizing reliability and efficiency.

#### **Biochemical Systems for Wastewater Treatment**

NASA is interested in biological or biochemical approaches to assist in purifying and recycling wastewater in confined spaces such as crewed spacecraft or space habitat cabins. Of special interest are novel approaches for removing carbon, nitrogen and phosphorus to potable or near potable concentrations, and reduction of biosolids. Systems should consider operating with low power, low consumables, low volume, high reliability and rapid



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deployment, as well as addressing multi-phase flow issues for reduced gravity.

#### Sub Topics:

##### Crew Accommodations and Waste Processing for Long Duration Missions Topic X3.02

Critical gaps exist with respect to interfaces between human accommodations and life support systems for long duration human missions beyond low Earth orbit. New technologies are needed for management and processing of human fecal waste and for clothing and laundry. Proposals should explicitly describe the weight, power, volume, and microgravity performance advantages.

### **Human Fecal Waste Management**

Microgravity technology is needed to collect, stabilize, safely, recover useful materials, and store human feces or its processed residuals. Simple low energy systems that recover water and sterilize/sanitize feces or mineralize it to minimal residuals (and perhaps gases or fuels) are desired. Complete systems are desired that include consideration of preprocessing, processing, and venting or containment for storage of the resultant residuals and/or recovered materials.

### **Clothing and Laundry Systems**

The requirements for crew clothing are balanced between appearance, comfort, wear, flammability and toxicity. Ideally, crew clothing should have durable flame resistance in a 34% O<sub>2</sub> (by volume) enriched environment. Fabrics must enable multiple crew wear cycles before cleaning/disposal.

The laundry system should remove or stabilize the combined contamination from perspiration salts, organics, dander and dust, preserve flame resistance properties, and use cleaning agents compatible with water recovery technologies, including both physiochemical and biological processes. Proposals using water for cleaning should use significantly less than 10 kg of water per kg of clothing cleaned.

#### Sub Topics:

##### Environmental Monitoring and Fire Protection for Spacecraft Autonomy Topic X3.03

### **Environmental Monitoring**

Monitoring technologies to ensure that the chemical and microbial content of the air and water environment of the crew habitat falls within acceptable limits, and life support system is functioning properly and efficiently, are sought. Required technology characteristics: 2-year shelf-life; functionality in microgravity, low pressure and elevated oxygen cabin environments. Significant improvements in miniaturization, operational reliability, life-time, self-calibration, and reduction of expendables should be demonstrated. Proposals should focus on one of the following areas:

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- Process control monitors for life support. Improved reliability for closed-loop feedback control system.
  - Trace toxic metals, trace organics in water.
  - Monitoring trace contaminants in both air and water with one instrument.
  - Microbial monitoring for water and surfaces using minimal consumables.
  - Optimal system control methods. Operate the life support system with optimal efficiency and reliability, using a carefully chosen suite of feedback and health monitors, and the associated control system.
  - Sensor suites. Determine, with robust technical analysis, the optimal number and location of sensors for the information that is needed, and efficient extraction of data from the suite of sensors.

## **Fire Protection**

Spacecraft fire protection technologies to detect the overheating or combustion of spacecraft materials by their particulate and/or gaseous signatures are also sought. These must be of suitable size, mass, and volume for a distributed sensor array. Technologies that detect smoke particulates and identify characteristics (mean particulate sizes or distribution) would also be useful. Catalytic or sorbent technologies suitable for the rapid removal of gases, especially CO, and particulate during a contingency response are desired.

### **Sub Topics:**

Spacecraft Cabin Ventilation and Thermal Control Topic X3.04

Future spacecraft will require quieter fans, better cabin air filtration, and advanced active thermal control systems.

## **Small Fan Aero-Acoustics**

Procedures and non-intrusive apparatus to measure the sound pressure levels in the inlet and exhaust duct of a candidate spacecraft ventilation fan are requested. Details of the aerodynamic design and the predicted aerodynamic performance of the candidate spacecraft cabin ventilation fan are reported in NASA CR-2010-216329, "Aerodynamic Design and Computational Analysis of a Spacecraft Cabin Ventilation Fan". The duct diameter for this fan (89 mm) falls below the minimum diameter required (150 mm) by ASHRAE Standard 68. The pressure rise at design point for this fan (925 Pa) exceeds the maximum recommended (750 Pa) in ISO 10302. The procedure that is requested to be developed should apply to fans of similar size and capacity (or greater) as the identified candidate spacecraft ventilation fan. The procedure developed should overcome the deficiencies in the standards by providing plots of overall sound power levels as a function of fan flow rate (from full flow to fully throttled conditions) along lines of constant fan rotational speed in the inlet and exhaust ducts. Values of the radial and circumferential duct mode sound power levels calculated from the pressure measurement should be recorded and made available for subsequent examination at all tested conditions. It also must be shown that the flow-induced microphone self-noise, if any, does not contribute significantly to the measured fan sound pressure levels or sound power levels. Validation of the measured fan sound power levels must be shown for a sub-set of the performance range using an alternate technique.

## **Methods of Particulate Separation and Filtration from Air**

Methods of particulate air filtration and/or separation targeting a range of particle sizes from tens of micron down to submicron in conjunction with efficient methods of regeneration are sought. The proposed technical solutions should reduce crew maintenance time and eliminate the need for consumable filter elements. These units should be able to handle large surges of particles and operate over very long periods. They should also be self-cleaning in-place (preferable) or off-line. Targeted technologies should be compact and lightweight, easily integrated with the

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spacecraft life support system, and provide viable methods for disposing of collected particulate matter while minimizing or eliminating direct contact by the crew.

## Active Thermal Control Systems

Thermal control systems will be required that can dissipate a wide range of heat loads with widely varying environments while using fewer of the limited spacecraft mass, volume and power resources. The thermal control system designs must accommodate high input heat fluxes at the heat acquisition source and harsh thermal environments at the heat rejection sink. Advances are sought for microgravity thermal control in the areas of:

- Innovative Thermal Components and System Architectures that are capable of operating over a wide range of heat loads in varying environments (for example, a 10:1 heat load range in environments ranging from 0 to 275K).
- Two-phase Heat Transfer Components and System Architectures for nuclear propulsion that will allow the acquisition, transport, and rejection of waste heat on the order of megawatts,.
- Heat rejection hardware for transient, cyclical applications using either phase change material heat exchangers or efficient evaporative heat sinks.
- Smaller, lighter high performance heat exchangers and coldplates.
- Low temperature external working fluids (a temperature limit of less than 150K with favorable thermophysical properties - e. g., viscosity and specific heat).
- Internal working fluids that are non-toxic, have favorable thermophysical properties, and are compatible with aluminum tubing (i.e., no corrosion for up to 10 years).
- Low mass, high conductance ratio thermal switches.
- Long-life, lightweight, efficient single-phase thermal control loop pumps capable of producing relatively high-pressure head (~4 atm).
- Dust tolerant long-life radiators.
- Variable area radiators (e. g., variable capacity heat pipe radiators or drainable radiators).
- Radiators compatible with inflatable volumes.
- Thermal systems and/or components to extend operational times for spacecraft under the extreme planetary environments, for example: the Venusian surface at approximately 460C and 98 atm.
- Flexible heat pipes.
- Methods to predict the performance of cryogenic multi-layer insulation blankets at 1 atmosphere and during ascent venting.
- Advanced thermal analysis tools that utilize stream processing to improve computational speed over conventional approaches. Possible candidates are: view factor calculation via ray tracing, orbital heating rate calculations, and thermal environment modeling.
- Inflatable/deployable shades to enhance reduce boiloff of cryogenic propellants in long-term storage in low earth orbit.

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Sub Topics:

Space Suit Pressure Garment and Airlock Technologies Topic X4.01

Advanced space suit pressure garment and airlock technologies are necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations.

Research is needed in the following space suit pressure garment areas:

- The space suit pressure garment requires innovative technologies that increase the life, comfort, mobility, and durability of gloves, self sealing materials to minimize the effects of small punctures or tears, and materials that are resistant to abrasion.
- Innovative garments that provide direct thermal control to crew member that minimize consumables are needed as well as materials for helmets that are scratch resistant or prevent fogging
- Technologies for space suit flexible thermal insulation suitable for use in vacuum and low ambient pressure are also needed.
- Light Weight Bearings for use in mobility joints in the pressure garment are needed.
- Advanced cooling garments that are highly efficient in removing metabolic heat and are low power consuming are needed.
- Advanced suit materials that provide radiation protection and reduce risks associated with electrical charging and shock.

Due to the expected large number of space walks that will be performed on the ISS beyond 2020 and future human space exploration missions, innovative technologies and designs for both microgravity and surface airlocks will also be needed.

Research is needed in the following space suit airlock area:

Technology development is needed for minimum gas loss airlocks providing quick exit and entry that can accommodate an incapacitated crew member, suit port/suit lock systems for docking a space suit to a dust mitigating entry/hatch in order for the space suit to remain in the airlock and prevent dust from entering the habitable environment.

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#### Sub Topics:

##### Space Suit Life Support Systems Topic X4.02

Advanced space suit life support systems are necessary for the successful support of the International Space Station (ISS) and future human space exploration missions for in-space microgravity EVA and planetary surface operations. Exploration missions will require a robust, lightweight, and maintainable Primary Life Support System (PLSS). The PLSS attaches to the space suit pressure garment and provides approximately an 8 hour supply of oxygen for breathing, suit pressurization, ventilation and CO<sub>2</sub> removal, and a thermal control system for crew member metabolic heat rejection. Innovative technologies are needed for high-pressure O<sub>2</sub> delivery, crewmember cooling, heat rejection, and removal of expired CO<sub>2</sub> and water vapor.

Focused research is needed in the following space suit life support system areas:

Feedwater Supply Bladder for PLSS - Focused research is needed to develop a shallow, translucent water bladder that will serve to pressurize the water loop for the new PLSS by using the suit pressure to compress the flexible bladder material. The unique aspect of this bladder includes a detection system to indicate via a signal that the remaining usable feed water is approximately .5 kg. Some additional requirements are: Usable capacity => 4.5 kg, Chemically inert to avoid chemical reactions with the feed water which may be DI water to potable standards, Approximate shape is a semi-circle with a diameter of 16 in (40.6 cm), Configuration is similar to an accumulator with a single inlet, 1/8in hose barb, and the Maximum Allowable Working Pressure => 20 psid (138 kPa differential).

PPCO<sub>2</sub>-H<sub>2</sub>O-O<sub>2</sub> Sensor for PLSS - Focused research is needed for a PLSS sensor that is able to measure critical life support constituents in a single combined flow-through sensor configuration. Free water tolerance is an important feature. Test and Shuttle/ISS space suit experience has shown this to be a real possibility that the sensor should tolerate.

#### Sub Topics:

##### Space Suit Radio, Sensors, Displays, Cameras, and Audio Topic X4.03

Future EVAs need advances in radio technologies, including antennas, tunable RF front-ends, and power amplifiers; low-power cameras; more accurate, reliable, and packaged core temperature, CO<sub>2</sub>, and biomedical sensors; user-friendly, minimally invasive crewmember information displays; and technologies that provide improvements in speech quality, listening quality and listening effort for in-helmet aural and vocal communications. Progress in these technologies will help ensure reliable communications, crew safety and comfort, and work efficiency and autonomy. The focus of this subtopic is to advance future EVA lightweight, compact, low-power technologies in five primary areas: radios, sensors, displays, cameras, and suit audio. The expectation for all of these EVA areas is that a report demonstrating the concept, requirements, design, and technical feasibility will be delivered at the end of Phase I, and that a working and fully functional device will be delivered at the end of Phase II.

The next-generation EVA radio needs to fulfill multiple functions while satisfying stringent requirements on size, weight and power (SWaP) consumption in the ISM S-band (2.4 - 2.483 GHz) and Ka-band (approximately 26 GHz). Ideally, eventual radio SwAP reductions would result in approximately 115 cubic inches, 3.5 - 5.5 pounds, and 15 watts total power consumption, respectively. Next-generation EVA radios will need to support multiple comm loops

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and point-to-point EVA comm., receive caution and warning messages from the vehicle and other EVA crew, receive, store, and display voice/text messaging to handle comm delays. Moreover, next-generation EVA antenna systems that effectively present uniform coverage around the suit are needed. Likewise, the next-generation EVA radio needs RF front-end architectures capable of presenting baseband or IF signals to waveform processing hardware in multiple bands. Radiation-hardened-by-design transceiver technologies improving upon current Single Event Upset tolerant approaches, along with cognitive technologies, are needed for future EVA exploration to Near Earth Asteroids and beyond.

In addition, advances in tunable technology that permit high Q factor, minimum insertion losses, and excellent linearity are desirable at the given S- and Ka-band Gigahertz frequencies for agility. The next-generation EVA radios will need to support voice, telemetry, and standard/high definition video data flows (up to 20 Mbps); ensure rapid upgrades via scalable, open, and modular architectures; and, advance power aware technologies to optimize efficiency, conserve EVA battery lifetime power, and prolong duration of EVA operations. Finally, no matter what type of transceiver architecture is used in the next-generation EVA radio, the power amplifier is always a key component to enable new functionality, and to minimize the power consumption of the whole radio. Current amplifiers suffer from one or many of the following drawbacks: a) insufficient power added efficiency, b) insufficient linearity performance and incompatibility with modern modulation signals, and c) incompatible with silicon CMOS technology. Most of the commercial PAs are based on III-V GaAs material system, which is more expensive compared to the CMOS fabrication processes. Additionally, the incompatibility with silicon CMOS technology makes it impossible to realize a fully integrated radio-on-a-chip system. Consequently, the implemented radio with the existing power amplifiers requires much more SwAP and higher fabrication costs. Advances are needed in the efficiency and linearity of power amplifiers for next-generation EVA radio applications.

Crew health and suit monitoring require advancement of lightweight CO<sub>2</sub>, biomedical (heart rate, blood OX, EKG) and core temperature sensors with reduced size, increased reliability, and greater packaging flexibility. Consequently, technologies are needed to provide high accuracy, low mass, and low-power sensors that measure flow rate, pressure, temperature, and relative humidity or dew point. All sensors must operate in a low pressure 100% O<sub>2</sub> environment with high humidity and may be exposed to liquid condensate.

Because missions must be designed with appropriate radiation shielding and adjusted to keep the radiation doses within tolerable limits, real-time, accurate, instantaneous and integrated radiation dose measurements and readout are needed such as novel dosimeter sensors. Given sufficient warning, astronauts can move to a more shielded part of the space vehicle and lessen dose impact. As cosmic rays impinge upon the vehicle leaving the magnetosphere, sensors are needed to determine the type of radiation and dose as well as reduce the potential risk of biological tissue damage.

Future EVAs need a user-friendly and minimally invasive crewmember information display device that provides significant task efficiency improvement for a broad range of EVA tasks. Current Head-Mounted Display and Near-to-Eye display technologies are a non-starter for EVA, because the display must be mechanically decoupled from the user's head in order to improve crew safety, comfort, and prevent display misalignment. This in turn makes for more difficult specifications for the eyebox (tolerance to misalignment before image goes out of focus), field of view (angle of the image created by the optics), and eye relief (working distance from the eye to the last optical element). Additionally, current Helmet-Mounted Display technologies are challenged in EVA applications due to geometric constraints within the helmet, and future display technologies must ensure suit displays can operate outside the suit protection in thermal, radiation, and vacuum environments as well as internally without imposing ignition hazards due to 100% oxygen environment. Key performance parameters (targets) include: Graphical Data Presentation: SXGA @ 40 deg FOV (possibly biocular); Decoupled from User's Head - Large Eyebox: 100 mm x 100mm x 50mm (D); Sunlight Readability: 500 fL inside visor, 1800 fL outside visor (>10 to 1 contrast).

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Future EVAs need to support high definition motion and high resolution imagery with ultra compact, low-power HD cameras and low loss compressed digital data output for RF transmissions and/or IP networks. Hemispherical and dynamic cameras are desired, where hemispherical cameras take video views of a crewmember (360 degrees), distorting those views thru optics and then undistorting those views via software on the ground to pan/zoom for total situational awareness. Dynamic cameras can take stills and motion in variable bandwidths, capture image based on link quality, change frame rates, interfaced to gigabit Ethernet and in a rad-tolerant package with dynamically reconfigure compression core(s) and common 'back-end' interfaces.

The space suit environment presents a unique challenge for capturing and transmitting speech communications to and from a crewmember. The in-suit acoustic environment is characterized by highly reflective surfaces, causing high levels of reverberation, as well as spacesuit-unique noise fields; and wide swings of static pressure levels. Due to these factors, the quality of speech delivered to and from the inside of a spacesuit helmet can be low and can have a negative effect on inbound and outbound speech intelligibility. The traditional approach to overcome the challenges of the spacesuit acoustic environment is to use a skullcap-based system of microphones and speakers. Cap-based systems are less successful, however, in attenuating high noise levels generated outside the spacesuit, and many logistical issues exist for head-mounted caps (e.g., crewmembers are not able to adjust the skullcap, headset or microphone booms during EVA operations, interference between the protuberances of the cap and other devices, comfort, hygiene, proper positioning and dislocation, and wire fatigue and blind mating of the connectors, multiple cap sizes to accommodate anthropometric variations in crew heads).

NASA is seeking technologies in support of improvements in speech intelligibility, speech quality, listening quality and listening effort for in-helmet aural and vocal communications. The specific focus of this SBIR subtopic is on improving the interface between crewmember and the acoustic pickup (microphones) and generation (speaker) systems. Devices are sought to improve or resolve acoustic, physical and technical problems (listed above) that have been associated with skullcap-mounted speakers and microphones, or allow for the elimination of skullcap-mounted speakers and microphones. In particular, voice communications systems are sought that have provided crewmembers with adequate speech intelligibility over background noise within, and external to, the spacesuit. Overall system performance must provide Mean Opinion Score (MOS) for Listening Quality (Lq) and Listening Effort (Le) of 3.9 or greater, or Articulation Index (AI) of .7 or better or 90% Intelligibility in the crewmember's native language for both inbound and outbound speech communication. Specific technologies of interest include, but are not limited to: acoustic modeling of the in-suit acoustic environment, including the ability to model structure-borne vibration in helmet and suit structures as well as transduction to and from the acoustic medium; low-mass, low-volume, low-distortion, space-qualified speakers with low variation in sensitivity with static pressure. Changes in speaker sensitivity should be less than 2 dB over the speech band with changes in static pressure between 3 and 18 psia; low-mass, ultra-low-volume (

#### Sub Topics:

##### Expandable Structures Topic X5.01

The SBIR subtopic area of Lightweight Inflatable Structures solicits innovative concepts to support the development of primary pressurized expandable habitat and storage modules for space exploration environments. Inflatable concepts should illustrate small efficient launch volumes and large deployment volumes. Concepts should also illustrate simple designs, efficient deployment techniques, lightweight materials, and potential for integrated hard points. Robustness, damage tolerance, and minor repair capabilities should also be considered in concept

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submittals. Airlock and window integration into the inflatable should also be considered.

Lightweight secondary structures for internal outfitting of the inflatable structure after deployment are also solicited. Lightweight concepts of interest include walkways, storage facilities, and hard points for utility or operational subsystems. Secondary structures should be packing and mass efficient, stiff-post deployment, redundant, modular, and multi-functional.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of a Phase II contract.

#### Sub Topics:

##### Advanced Fabrication and Manufacturing of Metallic and Polymer Matrix Composite Materials for Lightweight Structures Topic X5.02

The objective of the subtopic is to advance technology readiness levels of lightweight structures for launch vehicles and in-space applications, by using advanced materials and manufacturing techniques, resulting in structures having affordable, reliable, predictable performance with reduced costs. Performance metrics include: achieving adequate structural and weight performance; manufacturing and life cycle affordability analysis; verifiable practices for scale-up; validation of confidence in design, materials performance, and manufacturing processes; and quantitative risk reduction capability. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable materials/manufacturing technology combinations that can be scaled up for very large structures.

Materials topics should focus on lightweight monolithic metallic materials or Polymer Matrix Composites (PMC) that, in combination with design modifications, can significantly reduce structural mass. Research should include assessment of the material response to forming and joining methods and verification of post-forming properties. Also of interest are high temperature PMC materials for high performance composite structures (high temperature applications), particularly those which are compatible with current composite manufacturing techniques. High temperature PMCs should enable reduction of vehicle mass through elimination or reduction of thermal protection systems. Another area of interest covers development of lightweight damage-tolerant materials that are compatible with forming methods that can significantly reduce structural mass. Proposals to each area will be considered separately.

Fabrication technology topics should focus on near-net-shape and automated manufacturing methods, which can reduce structural weight, processing, and assembly steps, and minimize joints, resulting in increased reliability and reduced cost, and characterization of material response to forming and joining methods. Other interests include development of laboratory scale test methods to accurately simulate large scale manufacturing for use in screening material behavior. Research should include computational modeling and simulation of material behavior and testing to characterize material properties and validate manufacturing methods.



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#### Sub Topics:

##### Spaceflight Structural Sensor Systems and NDE Topic X5.03

There is a growing use for modular/low mass-volume, low power, low maintenance systems, that reduce or eliminate wiring, stand-alone smart sensor systems that provide answers as close to the sensor as practical and systems that are flexible in their applicability. The systems should allow for additions or changes in instrumentation late in the design/development process and enable relocation or upgrade on orbit. They reduce the complexities of standard wires and connectors and enable sensing functions in locations not normally accessible with previous technologies. They allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles and payloads supporting NASA missions.

There is also a need for modular/low mass/volume smart NDE sensors systems and associated software that enable effective use with minimum crew training or re-familiarization after extended periods of no use. Systems should include ability to perform inspections with minimal human interaction. These systems need to provide reliable assessments of the location and extent of damage with the minimal data transfer between vehicle and Earth. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments. Many applications require the ability to see through conductive and/or thermal insulating materials without contacting the surface. Sensors that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Structural design and material configurations are sought that can enhance NDE and monitoring. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who may only use the NDE tool infrequently.

#### Sub Topics:

##### Spacecraft Autonomy and Space Mission Automation Topic X6.01

Future human spaceflight missions will place crews at large distances and light-time delays from Earth, requiring novel capabilities for crews and ground to manage spacecraft consumables such as power, water, propellant and life support systems to prevent Loss of Mission (LOM) or Loss of Crew (LOC). This capability is necessary to handle events such as leaks or failures leading to unexpected expenditure of consumables coupled with lack of communications. If crews in the spacecraft must manage, plan and operate much of the mission themselves, NASA must migrate operations functionality from the flight control room to the vehicle for use by the crew. Migrating flight controller tools and procedures to the crew on-board the spacecraft would, even if technically possible, overburden the crew. Enabling these same monitoring, tracking, and management capabilities on-board the spacecraft for a small crew to use will require significant automation and decision support software. Required capabilities to enable future human spaceflight to distant destinations include:

- Enable on-board crew management of vehicle consumables that are currently flight controller responsibilities.
- Increase the onboard capability to detect and respond to unexpected consumables-management related events and faults without dependence on ground.

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- Reduce up-front and recurring software costs to produce flight-critical software.
  - Provide more efficient and cost effective ground based operations through automation of consumables management processes, and up-front and recurring mission operations software costs.

The same capabilities for enabling human spaceflight missions are directly applicable to efforts to automate the operation of unmanned aircraft flying in the National Airspace (NAS) and robotic planetary explorers.

### **Mission Operations Automation**

Peer-to-peer mission operations planning

Mixed initiative planning systems

Elicitation of mission planning constraints and preferences

Planning system software integration

### **Space Vehicle Automation**

Autonomous rendezvous and docking software

Integrated discrete and continuous control software

Long-duration high-reliability autonomous system

Power aware computing

### **Robotic Systems Automation**

Mutli-agent autonomous systems for mapping

Uncertainty management for mapping system

Uncertainty management for grasping robotic system

Uncertainty management for path planning and traversing

Emphasis of proposed efforts:

- Software proposals only, but emphasize hardware and operating systems the proposed software will run on (e.g., processors, sensors).
- In-space or Terrestrial applications (e.g., UAV mission management) are acceptable.

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- Proposals must demonstrate mission operations cost reduction by use of standards, open source software, staff reduction, and/or decrease of software integration costs.
  - Proposals must demonstrate autonomy software cost reduction by use of standards, demonstration of capability especially on long-duration missions, system integration, and/or open source software.

#### Sub Topics:

##### Radiation Hardened/Tolerant and Low Temperature Electronics and Processors Topic X6.02

Exploration flight projects, robotic precursors, and technology demonstrators that are designed to operate beyond low-earth orbit require avionic systems, components, and controllers that are capable of enduring the extreme temperature and radiation environments of deep space, the lunar surface, and eventually the Martian surface.

Spacecraft vehicle electronics will be required to operate across a wide temperature range and must be capable of enduring frequent (and often rapid) thermal-cycling. Packaging for these electronics must be able to accommodate the mechanical stress and fatigue associated with the thermal cycling. Spacecraft vehicle electronics must be radiation hardened for the target environment. They must be capable of operating through a minimum total ionizing dose (TID) of 300 krad (Si), provide fewer Single Event Upsets (SEUs) than 10<sup>-10</sup> to 10<sup>-11</sup> errors/bit-day, and provide single event latchup (SEL) immunity at linear energy transfer (LET) levels of 100 MeV cm<sup>2</sup>/mg (Si) or more. All three characteristics for radiation hardened electronics of TID, SEU and SEL are needed. Electronics hardened for thermal cycling and extreme temperature ranges should perform beyond the standard military specification range of -55°C to 125°C, running as low as -230°C or as high as 350°C.

Considering these target environment performance parameters for thermal and radiation extremes, proposals are sought in the following specific areas:

- Low power, high efficiency, radiation-hardened processor technologies.
- Technologies and techniques for environmentally hardened Field Programmable Gate Array (FPGA).
- Innovative radiation hardened volatile and nonvolatile memory technologies.
- Tightly-integrated electronic sensor and actuator modules that include power, command and control, and processing.
- Radiation hardened analog application specific integrated circuits (ASICs) for spacecraft power management and other applications.
- Radiation hardened DC-to-DC converters and point-of-load power distribution circuits.
- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature and wide-temperature electronic systems and components.
- Physics-based device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom mixed-signal and analog circuits.
- Circuit design and layout methodologies/techniques that facilitate improved radiation hardness and low-temperature (-230°C) analog and mixed-signal circuit performance.

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- Packaging capable of surviving numerous thermal cycles and tolerant of the extreme temperatures on the Moon and Mars. This includes the use of appropriate materials including substrates, die-attach, encapsulants, thermal compounds, etc.

#### Sub Topics:

##### Integrated System Health Management for Flexible Exploration Topic X6.03

Novel integrated system health management technologies will enable NASA's pursuit of a more sustainable and affordable approach to spaceflight. New heavy lift launch systems will incorporate new engines, propellants, materials, and combustion processes and will increase NASA's capabilities and significantly lower operations costs. Health management is essential for the safe and reliable operation of these complex systems. Innovative health management technologies are also essential for long-duration robotic precursor missions. Projects may focus on one or more relevant subsystems such as rocket engines, liquid propulsion systems, structures and mechanisms, thermal protection systems, power, avionics, life support, communications, and software. Specific technical areas of interest are methods and tools for:

- Early-stage design of health management functionality during the development of space systems, including failure detection methods, sensor types and locations that enable fault detection to line replaceable units.
- Sensor validation and robust state estimation in the presence of inherently unreliable sensors. Focus on data analysis and interpretation using legacy sensors.
- Model-based fault detection and isolation based on existing sensor suites that enables fault detection within time ranges to allow mission abort.
- Automatic construction of models used in model-based diagnostic strategies, limiting model construction times to 60% of the time required using manual methods.
- Prognostic techniques able to anticipate system degradation before loss of critical functions and enable further improvements in mission success probability, operational effectiveness, and automated recovery of function.
- Techniques that address the particular constraints of maintaining long-duration systems health of structures, mechanical parts, electronics, and software systems are also of interest.

#### Sub Topics:

##### Human Robotic Systems - Human Robot Interfaces Topic X7.01

The objective of this subtopic is to create human-robot interfaces that improve the human exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans. Ground controllers and astronauts will remotely operate robots using a range of control modes, over multiple distances (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

This subtopic seeks to develop new technologies that enable crew and ground controllers to better operate,

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monitor and supervise semi-autonomous robots. Of particular interest is software that improves robot operator productivity, situational awareness, and effectiveness.

Proposals are sought that address the following technology needs:

- Crew telerobotic interfaces. User interfaces that enable crew to remotely operate and monitor robots from inside a flight vehicle, habitat and/or during an extra-vehicular activity (EVA). User interfaces must be appropriate and relevant for use with near-term flight systems.
- Robot performance monitoring software. Software tools that enable remote monitoring of robot performance, detection of anomalies and contingencies, assessment of robot utilization and situational awareness of remote robot operations.
- Robot tactical planning software. Software tools that enable efficient, rapid handling of contingencies during robot tactical operations. This may involve a combination of embedded and user interface modules.
- Robot ground data systems. Systems and software for robot command planning and sequencing, telemetry processing, sensor/instrument data management, and automating ground control functions.

This subtopic does not solicit proposals for direct teloperation (e.g., joystick-based rate control), telepresence, or immersive virtual reality subsystems or systems.

#### Sub Topics:

##### Human-Robotic Systems - Mobility Subsystems Topic X7.02

The objective of this subtopic is to create human-robotic technologies (hardware and software) to improve the exploration of space. Robots can perform tasks to assist and off-load work from astronauts. Robots may perform this work before, in support of, or after humans.

Ground controllers and astronauts will remotely operate robots using a range of control modes (teleoperation to supervised autonomy), over multiple spatial ranges (shared-space, line-of-sight, in orbit, and interplanetary), and with a range of time-delay and communications bandwidth.

Proposals are sought that address the following technology needs:

- Subsystems to improve the transport of crew, instruments, and payloads on planetary surfaces, asteroids, in-space; and improve handling and maintenance of payloads and assets. This includes hazard detection sensors/perception, active suspension, grapppling/anchoring, legged locomotion, robot navigation, and infrastructure-free localization. As well as, tactile sensors, human-safe actuation, active structures, dexterous grasping, modular "plug and play" mechanisms for deployment and setup, small/lightweight

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excavation/drilling devices to enable subsurface access, and novel manipulation methods.

#### Sub Topics:

##### Fuel Cells and Electrolyzers Topic X8.01

Advanced primary fuel cell and regenerative fuel cell energy storage systems are enabling for various aspects of future Exploration missions. Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

#### **Proton Exchange Membrane (PEM) Fuel Cells and Electrolyzers**

Proposals that address technology advances related to the following issues for PEM fuel cell, electrolysis, and regenerative fuel cell systems are desired.

#### **Oxidation Resistant Gas Diffusion Layer (GDL)**

GDLs are integral to PEM fuel cell membrane-electrode-assemblies (MEAs). Traditional carbon or graphite based GDLs are very susceptible to oxidation under certain operating conditions in the pure oxygen environment of space fuel cell systems. This results in MEA degradation and shortened life. Proposals addressing the development of oxidation resistant GDLs that remain stable to oxidation in a pure oxygen environment, and provide improved performance and longer life are desired.

#### **Deionizing Water Treatment for High Pressure, High Temperature Water Electrolyzers**

Ultra high purity water is needed for NASA's high pressure, high temperature water electrolyzers. Technology is needed to remove ions within the water that is circulated over the catalyzed electrodes of the electrolyzer. Ions need to be reduced below TBD ppm prior to entering the water electrolyzer. The deionizer must function in flowing water at 2000 psi and 80°C.

#### **High System Pressure water Pump**

A water pump is needed to circulate water through a high-pressure water electrolyzer. The pump must meet the following criteria:

- Operating System pressure of >2000 psia.
- Minimum developed differential pressure of 30 psid.
- Operating temperature 20-90°C.
- Minimum liquid flow rate of 30 LPM.
- Chemically tolerant to water saturated with dissolved oxygen at 2000 psia, 90°C.

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- Tolerant to two-phase mixtures of gaseous oxygen and liquid water without losing pumping effectiveness.
  - Mass ? 2 kg.
  - Volume ? 0.75 liters.
  - Power Consumption ? 120 watts.

### **Instrumentation, Control, Health Monitoring, and Data Handling**

Highly reliable voltage monitors for batteries, fuel cells, electrolyzers, and regenerative fuel cells are needed having low mass and low parasitic power consumption. Up to 48 differential voltages (0-5 VDC) with a minimum of 120 VDC common mode rejection must be monitored for system health management over an operating temperature range of -20 to +40°C, and the system must be capable of being upgraded to meet a Grade-1 EEE reliability

### **Solid Oxide Fuel Cells and Electrolyzers**

Advanced primary Solid Oxide Fuel Cells (SOFC) and Electrolyzers offer notable advantages in certain space applications when integrated with, respectively, CH<sub>4</sub>/O<sub>2</sub> propulsion systems and systems for producing oxygen from planetary resources. In contrast to most terrestrial/commercial applications, solid oxide devices for spacecraft will operate on pure oxygen and clean fuel streams (e.g., pure methane.) New materials are required to enable their use in these applications. These devices typically operate at high temperatures (800-1000°C) and are expected to undergo on/off cycling in aerospace applications. Technology advances are sought that reduce the time required to get to operating temperature, enable hundreds of rapid start-up/shut-down cycles, and enable systems to accommodate large load swings without leakage or deposition of elemental carbon. Spacecraft solid oxide devices that operate with minimal active cooling are needed. Low recurring costs are not a priority for spacecraft fuel cell materials. Technology advances that reduce the weight and volume, improve the efficiency, life, safety, system simplicity and reliability of Solid Oxide Fuel Cells and Electrolyzers are desired. Proposals are sought which address the following areas:

#### **Advanced Primary SOFC Systems**

Their high temperature heat rejection and high efficiency power generation from methane and oxygen make primary SOFC's attractive for application to spacecraft with CH<sub>4</sub>/O<sub>2</sub> propulsion systems. Research directed towards improving the durability, efficiency, and reliability of SOFC systems fed by propellant-grade methane and oxygen is desired. Primary SOFC components and systems of interest:

- Have power outputs in the 1 to 3 kW range.
- Offer thermodynamic efficiencies of at least 70% (fuel source-to-DC output) when operating at the current draw corresponding to optimized specific power.
- Operate as specified after at least 300 start-up cycles (from cold to operating temperature within 5 minutes) and 300 shut-down cycles (from operating temperature to cold within 5 minutes).
- Operate as specified after at least 2500 hours of steady state operation on propellant-grade methane and oxygen.

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- Are cooled by way of conduction through the stack to a radiator exposed to space and/or by anode exhaust flow.

### **Advanced Solid Oxide Electrolyzers**

Their high temperature heat rejection and operation, along with high efficiency, make solid oxide electrolyzers attractive as the final step of producing oxygen from Lunar or Martian regolith by way of hydrogen or carbothermal reduction. They are also attractive components for Sabatier reactors producing methane from the Martian atmosphere. Research directed towards improving the durability, efficiency, and reliability of solid oxide electrolyzers is desired. Solid oxide electrolysis systems of interest:

- Require power inputs in the 1 to 3 kW range.
- Operate as specified after 10,000 hours of operation fed by water with mild contamination.
- Operate as specified after 100 start-up cycles (from cold to operating temperature within 5 minutes) and 100 shut-down cycles (from operating temperature to cold within 5 minutes).
- Offer thermodynamic efficiencies of at least 70% (DC-input to Lower Heating Value H<sub>2</sub> output) when operating at the current feed corresponding to rated power.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

#### **Sub Topics:**

##### **Space-Rated Batteries Topic X8.02**

Advanced battery systems are sought for future NASA Exploration missions to address requirements for safe, human-rated, high specific energy, high energy density, and high efficiency power systems. Possible applications include extravehicular activities, landers, and rovers. Areas of emphasis include advanced cell chemistries with aggressive weight and volume performance improvements and safety advancements over state-of-the-art lithium-based systems. Novel rechargeable battery chemistries with advanced non-toxic anode and cathode materials and nonflammable electrolytes are of particular interest. Priority will be given to efforts addressing novel cathode materials that can be paired with advanced silicon anodes.

The focus of this solicitation is on advanced concepts and cell components that provide weight and volume improvements and safety advancements that contribute to the following cell level metric goals:

- Specific energy >350 Wh/kg at C/2 (Fully charged or discharged in 2 hours).
- Energy density > 650 Wh/l at C/2.



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- Tolerance to abuse such as overcharge, external short-circuit, and over temperature.
  - Calendar life >10 years.
  - Cycle life >250 cycles at 100% depth of discharge.

Systems that combine all of the above characteristics and demonstrate a high degree of safety and radiation tolerance are desired. Cell safety devices such as shutdown separators, current limiting devices that inhibit thermal runaway, venting, and eliminate flame or fire; autonomous safety features that include safe, non-flammable, non-hazardous operation especially for human-rated applications are of particular interest.

Proposals should include analysis that demonstrates the potential of the proposed technology to meet the projected performance parameters. Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II breadboard demonstration, and when possible, deliver a prototype/ demonstration unit for functional and environmental testing at the completion of the Phase II contract.

#### Sub Topics:

##### Space Nuclear Power Systems Topic X8.03

NASA is developing fission power system technology for future space transportation and surface power applications using a stepwise approach. Early systems are envisioned in the 10 to 100 kWe range that utilize a 900 K liquid metal cooled reactor, dynamic power conversion, and water-based heat rejection. The anticipated design life is 8 to 15 years with no maintenance. Candidate mission applications include initial power sources for human outposts on the moon or Mars, and nuclear electric propulsion systems (NEP) for Mars cargo transport. A non-nuclear system ground test in thermal-vacuum is planned by NASA to validate technologies required to transfer reactor heat, convert the heat into electricity, reject waste heat, process the electrical output, and demonstrate overall system performance.

The primary goals for the early systems are low cost, high reliability, and long life. Proposals are solicited that could help supplement or augment the planned NASA system test. Specific areas for development include:

- 900 K NaK heat transport loops, including pumps and accumulators.
- 10 kWe-class Stirling and Brayton power conversion devices.
- 450 K water heat rejection loops, including pumps and accumulators.
- Composite radiator panels with embedded water heat pipes.
- Radiator deployment mechanisms and structures.
- Radiation tolerant materials and components.
- 120 V - 1k V power management and distribution (PMAD) for high power DC and AC systems, 1 kW to 100 kW respectively.

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The NASA system test is expected to provide the foundation for later systems in the multi-hundred kilowatt or megawatt range that utilize higher operating temperatures, alternative materials, and advanced components to improve system performance. For the later systems, specific power will be a key performance metric with goals of 30 kg/kWe at 100 kWe and 10 kg/kWe at 1 MWe. Possible mission applications include large NEP cargo vehicles, NEP piloted vehicles, and surface-based resource production plants. In addition to low cost, high reliability, and long life, the later systems should address the low system specific mass goal. Proposals are solicited that identify novel system concepts and methods to reduce mass and increase power output. Specific areas for development include:

- High temperature reactor fuels and structural materials.
- Reactor heat transport technologies for 1100 K and above.
- 100 kWe-class Brayton and Rankine power conversion devices.
- Waste heat rejection technologies for 500 K and above.

#### Sub Topics:

##### Advanced Photovoltaic Systems Topic X8.04

Advanced photovoltaic (PV) power generation and enabling power system technologies are sought for improvements in capability and reliability of PV power generation for space exploration missions. Power levels for PV applications may reach 100s of kWe. System and component technologies are sought that can deliver efficiency, cost, reliability, mass and volume improvements under various operating conditions.

PV technologies must enable or enhance the ability to provide low-cost, low mass and higher efficiency for power systems with particular emphasis on high power arrays to support solar electric propulsion missions. Examples of PV technology areas:

- Very large solar array concepts (>300kW) operating at high voltage (>200V).
- High voltage electronics for use in solar electric propulsion vehicles operating at bus voltages >200 VDC.
- Advanced concepts for array packaging, deployment and retraction.
- Advanced PV blanket and component technology/designs.
- Array concepts and module/component technologies that emphasize cost reduction (in materials, fabrication and testing).
- Automated/modular fabrication methods.
- Component and material availability/ high volume production capability.
- Ground testability/ space qualification for large array structures.

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Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. A major focus will be on the demonstration of dual-use technologies that address exploration mission needs but also benefit clean/ renewable energy for terrestrial applications.

#### Sub Topics:

##### Ablative Thermal Protection Systems Topic X9.01

The technologies described below support the goal of developing higher performance ablative TPS materials for future Exploration missions. Developments are sought for ablative TPS materials and heat shield systems that exhibit maximum robustness, reliability and survivability while maintaining minimum mass requirements, and are capable of enduring severe combined convective and radiative heating, including: development of acreage (main body, non-leading edge) materials, adhesives, joints, penetrations, and seals. Three classes of materials will be required:

- One class of materials, for Mars aerocapture and entry for a rigid mid L/D (lift to drag ratio) shaped vehicle, will need to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm<sup>2</sup> (primarily convective) and integrated heat loads of up to 55 kJ/cm<sup>2</sup>, and the second at heat fluxes of 100-200 W/cm<sup>2</sup> and integrated heat loads of up to 25 kJ/cm<sup>2</sup>. These materials or material systems must improve on the current state-of-the-art recession rates of 0.25 mm/s at heating rates of 200 W/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm<sup>2</sup> required to maintain a bondline temperature below 250°C
- The second class of materials, for Mars aerocapture and entry for a hypersonic deployable aerodynamic decelerator, will need to survive a dual heating exposure, with the first at heat fluxes of 100-200 W/cm<sup>2</sup> (primarily convective) and integrated heat loads of 10 kJ/cm<sup>2</sup> and the second at heat fluxes of 30-50 W/cm<sup>2</sup> and heat loads of 5 kJ/cm<sup>2</sup>. These materials may be either flexible or deployable.
- The third class of materials, for Mars return, will need to survive heat fluxes of 1500-2500 W/cm<sup>2</sup>, with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm<sup>2</sup>. These materials, or material systems must improve on the current state-of-the-art recession rates of 1.00 mm/s at heating rates of 200 W/cm<sup>2</sup> and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm<sup>2</sup>, required to maintain a bondline temperature below 250°C.

In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data will lead to higher fidelity design tools, risk reduction, decreased heat shield mass and increases in direct payload. The heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values.

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Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void detection requirements are on the order of 6-mm, and bondline defect detection requirements are on the order of 25.4-mm by 25.4-mm by the thickness of the adhesive.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring. There is a specific need for improved models for low and mid density as well as multi-layered charring ablators (with different chemical composition in each layer). Consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver, should be included in the modeling efforts.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

Sub Topics:

### **Commercial Development of Active Debris Remediation (ADR) Services**

Advanced Integrated Hypersonic Entry Systems Topic X9.02

The technologies below support the goal of developing advanced integrated hypersonic entry systems that meet the longer-term goals of realizing larger payload masses for future Exploration missions.

Advanced integrated thermal protection systems are sought that address:

- Thermal performance efficiency (i.e., ablation vs. conduction).
- In-depth thermal insulation performance (i.e., material thermal conductivity and heat capacity vs. areal density).
- Systems thermal-structural performance.
- System integration and integrity.

Such integrated systems would not necessarily separate the ablative TPS material system from the underlying sub-structure, as is the case for most current NASA heat shield solutions. Instead, such integrated solutions may show benefits of technologies such as hot structures and/or multi-layer systems to improve the overall robustness of the integrated heat shield while reducing its overall mass. The primary performance metrics for concepts in this class are increased reliability, reduced areal mass, and/or reduced life cycle costs over the current state of the art.

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Advanced multi-purpose TPS solutions are sought that not only serve to protect the entry vehicle during primary planetary entry, but also show significant added benefits to protect from other natural or induced environments including: MMOD, solar radiation, cosmic radiation, passive thermal insulation, dual pulse heating (e.g., aero capture followed by entry). Such multi-purpose materials or systems must show significant additional secondary benefits relative to current TPS materials and systems while maintaining the primary thermal protection efficiencies of current materials/systems. The primary performance metrics for concepts in this class are reduced areal mass for the combined functions over the current state of the art.

Integrated entry vehicle conceptual development is sought that allow for very high mass (> 20 mT) payloads for Earth and Mars entry applications. Such concepts will require an integrated solution approach that considers: TPS, structures, aerodynamic performance (e.g., L/D), controllability, deployment, packaging efficiency, system robustness/reliability, and practical constraints (e.g., launch shroud limits, ballistic coefficients, EDL sequence requirements, mass efficiency). Such novel system designs may include slender or winged bodies, deployable or inflatable entry systems as well as dual use strategies (e.g., combined launch shroud and entry vehicle). New concepts are enabling for this class of vehicle. Key performance metrics for the overall design are system mass, reliability, complexity, and life cycle cost.

Advances in Multidisciplinary Design Optimization (MDO) are sought specifically in application to address combined aerothermal environments, material response, vehicle thermal-structural performance, vehicle shape, vehicle size, aerodynamic stability, mass, vehicle entry trajectory/GN&C (Guidance, Navigation and Control), and cross-range, characterizing the entry vehicle design problem.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

#### Sub Topics:

##### Cryogenic Fluid Management Technologies Topic X10.01

This topic solicits technologies related to cryogenic propellant storage, transfer, and instrumentation to support NASA's exploration goals. Proposed technologies should feature enhanced safety, reliability, long-term space use, economic efficiency over current state-of-the-art, or enabling technologies to allow NASA to meet future space exploration goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions. Specifically:

- Innovative concepts for cryogenic fluid instrumentation are solicited to enable accurate measurement of propellant mass in low-gravity storage tanks, sensors to detect in-space and on-pad leaks from the storage system, minimally invasive cryogenic liquid mass flow measurement sensors, including cryogenic two-

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phase flow.

- Passive thermal control for Zero Boil-Off (ZBO) storage of cryogenics for both long term (>200 days) and short term (~14 days) in all mission environments. Insulation systems that can also serve as Micrometeoroid/orbital debris (MMOD) protection and are self-healing are also desired.
- Active thermal control for long term ZBO storage for space applications. Technologies include 20K cryocoolers and integration techniques, heat exchangers, distributed cooling, and circulators.
- Zero gravity cryogenic control devices including thermodynamic vent systems, spray bars, mixers, and liquid acquisition devices.
- Advanced spacecraft valve actuators using piezoelectric ceramics. Actuators that can reduce the size and power while minimizing heat leak and increasing reliability.
- Large scale propellant conditioning and densification technologies for zero loss propellant storage and transfer. Specific component technologies include compact, efficient and economical cryogenic compressors, cryocoolers and integration techniques, Joule-Thompson orifices, vapor shielded transfer lines, and heat exchangers.
- Liquefaction of oxygen for in space resource utilization applications. This includes passive cooling with low temperature radiators, cryocooler liquefaction, or open cycle systems that work with HP electrolysis.
- Processes or components/instrumentation that can reduce or eliminate helium usage. This includes real time purge gas concentration visibility, helium capture and purification technology, and alternatives to helium use such as hydrogen gas purges or advanced insulation systems.

#### Sub Topics:

##### Radiation Shielding Materials Systems Topic X11.01

Advances in radiation shielding materials technologies and systems are needed to protect humans from the hazards of space radiation during NASA missions. The primary areas of interest for this 2011 solicitation are radiation shielding materials systems for long-duration galactic cosmic radiation (GCR) and solar energetic particles (SEP) protection. Neutron protection and high-energy electron protection are also of interest. Research should be conducted to demonstrate technical feasibility during Phase I and to show a path toward a Phase II technology demonstration.

Physical, mechanical, structural, and/or other relevant characterization data to validate and qualify multifunctional radiation shielding materials should be demonstrated. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements include the following:

- Innovative tailored materials for lightweight radiation shielding of humans.
- Innovative, multifunctional, integrated, or multipurpose structures (primary or secondary structures) for lightweight radiation shielding of humans.
- Innovative processes for developing radiation shielding materials.

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- Smart, or sensing, radiation shielding materials.
  - Radiation shielding materials demonstration experiments for MISSE (Materials International Space Station Experiment) or other ISS experiments.

#### Sub Topics:

##### Integrated Advanced Alert/Warning Systems for Solar Proton Events Topic X11.02

Advances are needed in alerts/warnings and risk assessment models that give mission planners, flight control teams and crews sufficient advanced warning of impending Solar Proton Event impact. Research and development should be targeted which leverages modeling techniques used throughout terrestrial weather for extreme event assessment. There is particular interest in development of models capable of delivering the probability of no SPE occurrence in a 24-hour time period, i.e., an "All-Clear" forecast.

Forecast techniques should utilize the historical record of archived SPEs to characterize model forecast validity in terms accepted metrics, i.e., skill score, false alarm rates, etc. Specific areas in which SBIR-developed technologies can contribute to NASA's overall mission requirements include the following:

Innovative forecasting solutions that leverage model development in other areas such as ensemble forecasting of hurricane tracks, flooding, financial market behavior, and earthquake prediction.

Innovative methods that integrate historical trending, real-time data, and fundamental physics-based models into advance warning and detection systems.

#### Sub Topics:

##### Crew Exercise Systems Topic X12.01

NASA seeks compact, low mass, low power, hi life-cycle, force-generating components for application to future crew exercise equipment - capable of providing aerobic and resistive (>700 lbs) loads over a range of load increments of 5 lbs. for each load setting 100 lbs., and with adjustable stroke range up to 70 inches, while providing return: pull stroke load ratios of 0.9:1.0 or greater (e.g., 1.0:1.0 better, or 1.1:1.0 best) over the entire range of motion.

Phase I Deliverable: Fully developed concept complete with feasibility and top-level drawings/computational methodology as applicable. A breadboard or prototype system is highly desired.

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Sub Topics:

Portable Load Sensing Systems Topic X12.02

NASA seeks a portable, force/load measurement system capable of being integrated into existing International Space Station (ISS) exercise systems. During long duration spaceflight, exercise countermeasures are prescribed to mitigate bone and muscle loss. However, advancement of these exercise prescriptions may require biomechanical analysis of exercise on orbit. Output parameters from the proposed device must operate in the bandwidth from 0-100Hz and be able to be synchronized with existing analog data systems. Vertical and shear forces are required and the portable system should be low-maintenance, durable, easy to set-up and calibrate, non-disruptive to exercise form (e.g., running, squat, dead lift, and calf raises), reliable, accurate (

Phase I Deliverable: Fully developed concept complete with feasibility and top-level drawings/computational methodology as applicable. A breadboard or prototype system is highly desired.

Sub Topics:

Smart Phone Driven Blood-Based Diagnostics Topic X13.01

As user applications pervade the field of telemedicine, smart phones provide a robust, reconfigurable platform capable of communications, computations and various functions (i.e., imaging, video, power source, signal processing) that will continue to expand at an accelerated pace. By leveraging this technology, NASA seeks to exploit the smart phone for blood-based diagnostics to develop an analytical device that can determine basic metabolic (Chem8), blood gas ( $\text{PaO}_2$ ,  $\text{PaCO}_2$ ,  $\text{SaO}_2$ ,  $\text{HCO}_3$ , pH), cardiac (troponin I, CK-MB, total cholesterol, HDL, LDL, VDL, triglycerides and lipoproteins) and liver/renal (total bilirubin, direct bilirubin, ALP, ALT, AST) panels. These panels are representative of the operational and research requirements for space exploration related point of care diagnostics.

The diagnostic device must interface to a smart phone that will drive the device's electronics and/or optics; or use the built-in features of the phone to interrogate the diagnostic device. The described diagnostic component is to be no larger than the phone itself. The microfluidic device must also be reusable or extremely compact if disposable, and minimize reagent consumption. Other requirements to consider are analytical times in two minutes or less, strategies for operational capability up to 144 hours on battery power and a long shelf-life (> 36 months).

The Phase I effort will seek to demonstrate the feasibility of one diagnostic panel in the smart phone format. The Phase II effort will demonstrate at least two of the above stated panels in an analytical component that interfaces to a cell phone, and provides a path towards FDA approval or similar.



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## NASA Deliverable: Functional Diagnostic System

### Sub Topics:

#### Non-Wet Prep Electrodes Topic X13.02

Although physiological monitoring has been conducted since the earliest human flights, there has not been substantial improvement in the technology of the sensors used in space since those early years. The current systems on the International Space Station (ISS) are still using wet-prep electrodes - which are time consuming and inconvenient, requiring shaving, application of electrodes, signal checks, and management of lead wires. Skin irritation sometimes develops from the electrode's interactions with roughened skin. And the signals are still subject to noise, corruption, and loss.

NASA desires a non-wet prep sensor system that:

- Is easy to don/doff (requires no shaving or skin prep), has no disposables, and can be worn comfortably for 48 hours.
- Maintains signal integrity at clinical quality (meets or exceeds ANSI/AAMI EC11 Standard for Diagnostic Electrocardiographic Devices) during rigorous exercise.
- Solutions that partially involve software (as opposed to strictly hardware) are acceptable, but any developed software code must be easily integrated into the ECG software system(s) used by NASA and not just into the given company's proprietary and/or standalone product.

## NASA Deliverable: Functioning sensor system

### Sub Topics:

#### Virtual Reality and World Technologies for Team Training Approaches Topic X14.01

This subtopic is to develop a virtual reality training environment to support pre-mission and just-in-time training for exploration crews and controllers. The training should encompass individual interactions with other team members as well as with the environment.

NASA wishes to identify how virtual reality and world technologies could be used to train crews and controllers on

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topics such as cross-cultural interactions, leadership, psychological support, and effective interactions with other team members or artificial intelligent agents while attempting to complete complicated, multi-agent (human or robotic) tasks.

The proposal should provide a framework describing:

- The virtual environment to be developed.
- Platform in which training will be experienced.
- How the training will allow the interaction with others (multi-player online or artificial intelligent agents), specific suggestions as to how to evaluate the training module's effectiveness and prediction of team performance and other important team outcomes and an assessment to determine the feasibility of the proposed training modules in the technical skill domains.

NASA Deliverables: Phase I deliverable should yield a proof of concept which includes both a literature review that encompasses an assessment of current knowledge of virtual reality technologies and its use in team training. In addition, the following deliverables will be required:

- A requirements document for such a training module.
- An evaluation plan for assessing the effectiveness of the training module on team outcomes.

The subsequent Phase II deliverable would provide a prototype of specific training modules that can demonstrate improved team performance (including task performance metrics) by utilizing these training technologies.

#### Sub Topics:

A New Technique for Automated Analyses of Raw Operational Videos Topic X15.01

Develop a software tool that automatically processes raw motion video footage (from a single conventional 2D camera) of a crew (spacecraft or ground) during a space mission.

Such a tool is needed to address vehicle/habitat design issues, as well as crew-to-crew interaction issues, on the

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ground. For example, unprocessed space mission operational videos down linked from a spacecraft that involve humans as the subjects of interest need to be analyzed on the ground for their motion and behavioral health information.

#### Requirements:

- The raw video data shall be video footages from a single conventional 2D camera and with no special lighting or fiduciary markers.
- The processed data shall contain the subjects' geometric information (position, movement, acceleration) relative to their operational environment and crewmates.
- A "tool chest" shall be available for visualization aids, velocity computations, etc. For visualization aids, the tool chest shall enable the user to specify areas or actions of interest. The software shall then locate, mark, count, etc. to indicate how many times the crew accessed a piece of hardware, traversed a path, reached above their heads, etc.

Desirable: 3D information extraction - ability to extract 3D information from the raw video to enable high-precision human motion analyses using the software's tool chest.

Phase I Deliverable: Algorithm

Phase II Deliverable: Functional software prototype

#### Sub Topics:

Advanced Food Technologies Topic X15.02

The purpose of the NASA Advanced Food Technology Project is to develop, evaluate and deliver food technologies for human centered spacecraft that will support crews on long duration missions beyond low-Earth orbit. Safe, nutritious, acceptable, and varied shelf-stable foods with a shelf life of 3 - 5 years will be required to support the crew during these exploration missions. Concurrently, the food system must efficiently balance appropriate vehicle resources such as mass, volume, water, air, waste, power, and crew time.

Refrigeration and freezing require dispensable resource utilization, so NASA provisions consist solely of shelf stable foods. Stability is achieved by thermal or irradiative processing to kill the microorganisms in the food or drying to prevent viability of the microorganisms. These methods do impact the micronutrients within the food substrate. Environmental factors (such as moisture ingress and oxidation) are also capable of compromising the nutrient content over the shelf life of the food. Since the food system is the designated source of nutrition to the crew, a significant loss in nutrient availability could significantly jeopardize the health and performance of the crew. Optimal nutritional content of the food for up to five years will ensure that the food can support crew performance and help protect their bodies from deficiencies that cause disease.

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Vitamin content in NASA foods, such as Vitamin C, Vitamin A, thiamin, and folic acid, is degraded during processing and as the product ages in storage. The goal is to develop a system that protects the vitamins from this degradation at ambient temperatures over a five year duration. Possible technologies that could be investigated to protect food ingredients from biological and chemical degradation of components over time include nanoscale technologies (e.g., encapsulation), biosensors, novel food ingredients, and controlled-release systems. Technologies or systems that could aid in increasing the bioavailability of the nutrients should also be considered.

Phase I Requirements: Phase I should concentrate on the scientific, technical, and commercial merit and feasibility of the proposed innovation resulting in a feasibility report and concept, complete with analyses.

NASA Deliverable: A system which will result in higher nutrient content in shelf stable foods.

#### Sub Topics:

##### Radiation Measurement Technologies Topic X16.01

NASA has a need for compact active radiation detection systems that can meet stringent size, power, and performance requirements. These include real-time personal monitors and area monitors that can be used on the ISS as well as on future missions beyond LEO. Ending the Space Shuttle program will increase the need to replace the current passive monitoring technologies on the ISS with active ones to reduce up and down mass. Also, as missions extend beyond LEO there will be further premium on reduced size, mass, and power for radiation detection technologies. To achieve such reductions, there will be an increasing need for reliable miniaturized components such as sensors, photomultipliers, data processors, power supplies, and the like that can be used to enhance radiation detection technologies as they develop. Advanced technologies up to technology readiness level (TRL) 4 are requested in these and related areas useful to NASA. Also, such advances would likely have potential customers outside NASA and in the commercial sector.

Metric and desired performance range:

#### **Personal Monitors**

Sensitive to charged particles with LET of 0.2 to 500 keV/μm and detect charged particles (including protons) with energies 30 MeV/n to 1000 MeV/n. Design goals for mass should be 0.25 kg and for volume, 250 cm<sup>3</sup>. The monitor should be able to measure dose rate and dose-equivalent rate at both ambient conditions in space (0.01 mGy/hr) and during a large solar particle event (100 mGy/hr). Total power requirement should be in the 1 W range. Monitors shall perform data reduction internally and display dosimetry data in real time.

#### **Area Monitors**

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Same as Personal Monitors but extend LET to 1000 keV/μm and must also detect neutrons between 0.5 MeV and 150 MeV. Design goals for mass should be 1 kg and for volume should be 1000 cm<sup>3</sup>. Total power requirement should be less than 2 W. Monitors shall perform data reduction internally and display dosimetry data in real time.

## Components

These may include but are not limited to compact sensors with excellent response to space radiation (e.g., novel scintillation crystals, organic semiconductors, photodiodes), compact low-noise solid state photomultipliers that require less than 0.5 W of power, data processors not to exceed 0.2 W that can perform multi-channel analysis, low noise power supplies that require less than 0.3 W of power.

Phase I Deliverables: Proof of concept of the technologies requested.

Phase II Deliverables: Prototypes or components of the monitoring technologies meeting the requirements indicated.

## Sub Topics:

Alternative Methods for Ambient Preservation of Human Biological Samples During Extended Spaceflight and Planetary Operations Topic X17.01

Addressing multiple Human Research Program (HRP) human health and performance risks and knowledge gaps across various disciplines requires collection, preservation and analysis of biological samples from human subjects during a space mission, a common practice in clinical diagnostic medicine. However, the spaceflight environment affords unique challenges for the processing, storage and transport of biological specimens, due to highly constrained resources, such as very limited conditioned stowage (mass and volume requiring storage in refrigerators or freezers) to keep and return the biospecimens. This subtopic aims to mitigate those space mission constraints by means of innovative approaches for the long duration ambient temperature preservation of human biological samples, particularly blood and urine, while maintaining the integrity of a wide array of biomedically significant molecular markers for subsequent post-mission processing and analysis.

This subtopic seeks proposals for novel approaches to preserve analytes of clinical and research interest in human blood and urine samples for a minimum of one year at ambient temperature. Target blood analytes to be preserved include those in the Comprehensive Metabolic Panel: glucose, calcium, albumin, total protein, electrolytes (sodium, potassium, bicarbonate, chloride), kidney tests (blood urea nitrogen, creatinine), and liver tests (bilirubin, alkaline phosphatase, alanine amino transferase, aspartate amino transferase). Additional blood markers to be preserved include N-telopeptide, sulfate, highly specific C-reactive protein, tumor necrosis factor, interleukin-1, interleukin-6, 8-hydroxy-2-deoxy-guanosine, vitamin D, homocysteine, and selenium. For urine samples, the following analytes should be preserved: creatinine, cortisol, N- and C-telopeptides, hydroxyproline, 4-pyridoxic acid, 3-methylhistidine,

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G-carboxyglutamic acid, 8-hydroxy-2-deoxy-guanosine, uric acid, phosphorus, citrate, sulfate, oxalate, calcium, sodium, potassium, magnesium, and chloride. The proposed technology should be low-resource, low-footprint, and should involve a low volume of supplies/consumables, which do not require refrigeration or freezing for storage.

NASA Deliverable: Prototype functional system for long duration room temperature preservation of human blood and/or urine biospecimens, demonstrating integrity for a subset of the target analytes (in Phase I).

Sub Topics:

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